STRATIGRAPHY, STRUCTURE AND GEOLOGICAL HISTORY OF MID-CRETACEOUS SEDIMENTARY ROCKS ACROSS THE TORLESSE-LIKE/NON TORLESSE BOUNDARY IN THE SAWTOOTH RANGE - COVERHAM AREA, MARLBOROUGH.

A thesis
submitted in partial fulfillment
of the requirements for the Degree
of
Master of Science in Geology
in the
University of Canterbury
by
D.D. Ritchie

University of Canterbury

1986

CONTENTS

Page

Page

Page

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES (Map Pocket)

ABSTRACT

This thesis describes the geology of an approximately 100km² area lying between the Clarence River and Kekerengu. The objectives were to determine the relationship of the "Torlesse-like" Sawtooth Group to the late Early Cretaceous Coverham Group; to determine the relationship between the coeval Split Rock and Burnt Creek Formations within the Coverham Group; and to investigate the nature of Cretaceous events which led to the traditional differentiation into older Torlesse type "basement" and younger Cretaceous "cover".

Geological mapping indicates the presence of three packets (Glencoe, Pikes and Coverham Blocks) of sedimentary rocks separated by the major Ouse and Pikes Faults. These packets comprise probable submarine fan flysch, massive sandstone, massive siltstone, acid tuffs and conglomerate of Sawtooth Group (Torlesse-like Urutawan - Motuan) unconformably overlain by probable slope basin flysch, massive siltstone, *Inoceramus* shellbed, and conglomerate of Coverham Group (non-Torlesse). The unconformity is most commonly angular but in a few places is a more subtle paraconformity. A further minor unconformity occurs at the base of the Ouse Member within the Split Rock Formation of the Coverham Group and is thought to reflect the presence of the growing Ouse Anticline.

The Coverham Group rocks have similar Motuan - Teratan ages on each side of the Ouse Fault. The Split Rock Formation, previously used only for rocks in the middle Clarence Valley, has been extended to the Coverham area and used for rocks west of the Ouse Fault. The partly coeval Burnt Creek Formation east of the Ouse Fault was probably deposited some distance from the Split Rock Formation in a different basin separated by a structural high. They were juxtaposed by low angle reverse movement on the Fault in the Late Cretaceous.

Structural/deformation characteristics cannot be used as criteria for separating the Torlesse-like rocks from non-Torlesse

rocks in the study area. It is dangerous to assume that 'Torlesseness' is a certain and particular state of deformation. Both the Torlesse (Sawtooth) and Coverham Group rocks exhibit a whole spectrum of deformation from 'broken formation' to more or less undisturbed beds.

The pattern of deposition and deformation suggests an accretionary prism setting for these rocks. Sawtooth Group rocks are likely to represent 'younger' Pahau Terrane rocks which were deformed by a single intra-Motuan event either tectonic or perhaps a huge submarine slide, creating widespread unconformity between them and the Coverham Group slope deposits. Continuing instability is likely to have led to growing folds and further minor unconformities.

The termination of the Rangitata Orogeny occurred in a progressive and evolutionary way representing a mid-Late Cretaceous change from a compressional subduction regime to a tensional rifting regime.

Andesitic-rhyolitic volcanism was common in the late Early Cretaceous.

CHAPTER I

INTRODUCTION

1.1 LOCATION

The area mapped (*fig. 1.1*) consists of approximately 100km² of dissected hill and mountain country at the northern end of the Seaward Kaikoura Range, Marlborough. Its boundaries are Mead Stream in the west, the north bank of the Clarence River in the south, the Kekerengu River in the east, and Benmore Stream to Swale Stream in the north. The Clarence River provides a formidable barrier being unfordable for much of the year.

Access is via a vehicle track which skirts the northern boundary of the study area running between Kekerengu on the Kaikoura coast, and the middle Clarence Valley. South of this road, access is by foot.

1.2 GEOLOGICAL SETTING

The study area covers the controversial intra-Cretaceous boundary between rocks similar to those of the Permian-Mesozoic Torlesse terrane (Coombs et. al. 1976, Bradshaw et. al. 1981) and the overlying late Early Cretaceous Coverham Group.

Torlesse terrane rocks outcrop over most of the eastern two-thirds of the South Island (*fig. 1.1*), generally becoming younger in an easterly direction, from a Permian age in South Canterbury, to Cretaceous in Marlborough (Campbell and Warren 1965, Raine et. al. 1981). They primarily consist of monotonous sequences of steeply dipping, interbedded sandstones and siltstones with rare conglomerate, basic volcanics, chert and limestone. Conglomerates are more prevalent to the north and east than in the older rocks (Andrews et. al. 1976). To the south and west they grade into the Haast Schists but to the northeast they are

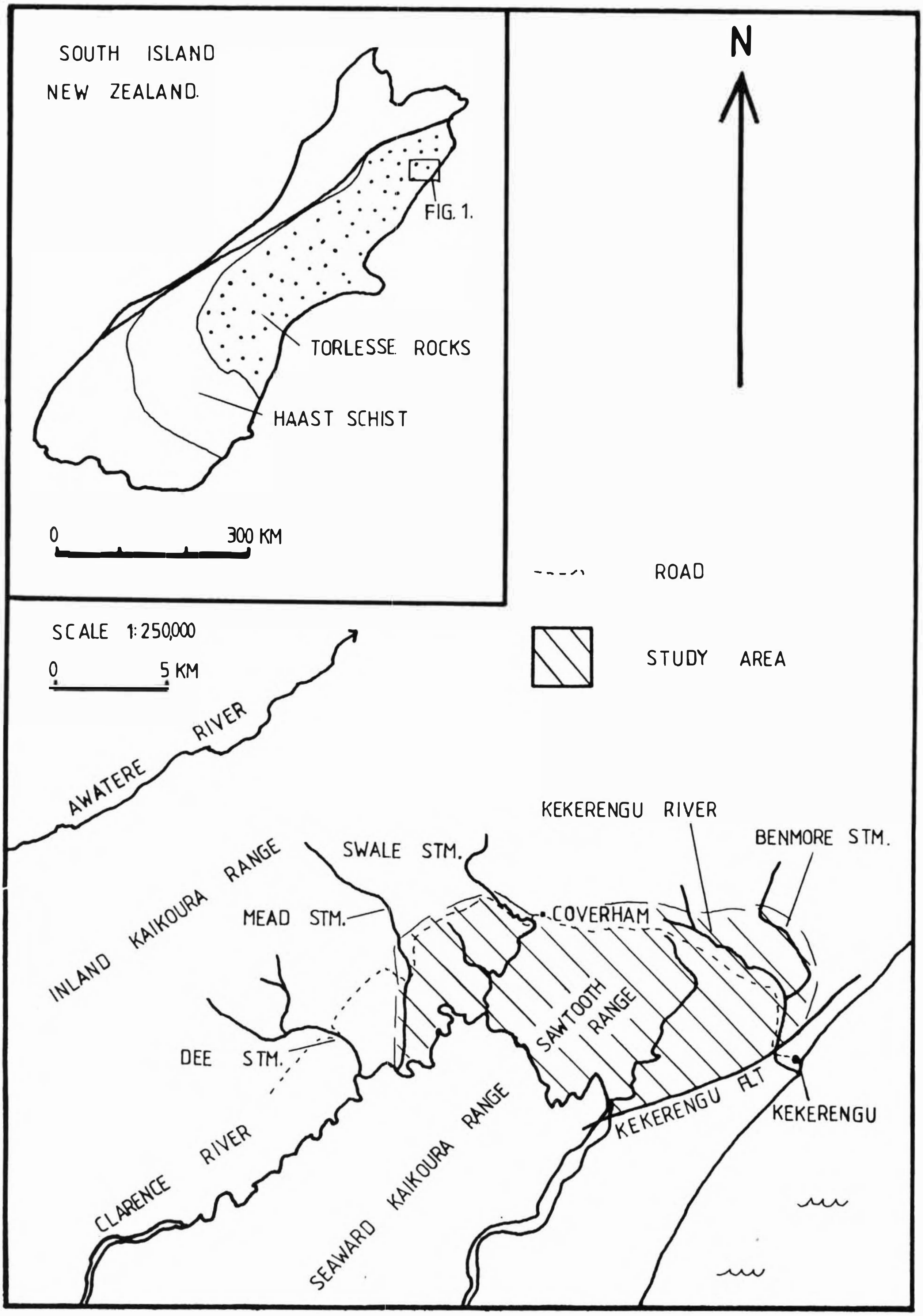


Figure 1.1 Location map

overlain by other Cretaceous sedimentary rocks. The Torlesse terrane has been divided into 'older' and 'younger' parts or Rakaia and Pahau Terranes respectively, which are separated by the Esk Head Melange (Bishop et. al. 1985). The Rakaia Terrane is thought to have been emplaced from the east and amalgamated to the Caples Terrane in the early Jurassic (Bradshaw et. al. 1981, Adams and Gabites 1985) during an early episode of the Rangitata Orogeny. The Pahau Terrane rocks are probably an accretionary complex.

In the study area, the Torlesse-like rocks were named the Sawtooth Group (Lensen in Suggate et. al. 1978) of Cretaceous age. They are likely to be part of the Pahau Terrane (op. cit.). Coverham Group rocks comprising sandstones, siltstones and conglomerates, overlie Sawtooth Group, dipping moderately, and facing to the north and west. The Group's lithologies are very similar to those of the Sawtooth but less rich in sandstone, and in addition the rocks are less metamorphosed and deformed. Their age is early Cretaceous.

Structurally, the area lies between and is consequently influenced by the Clarence and Kekerengu Faults, the latter of which at least, is one of a number of major dextral transcurrent faults which occur within the 200km wide Pacific/Indian plate boundary zone. This part of Marlborough is thought to be a southern extension of the East Coast Deformed Belt (Sporli 1980, Pettinga 1982) which consists of a series of imbricate thrust slices thought to represent an accretionary prism.

The area provides an abundance of excellent outcrop. There is a marked induration induced topographic break between the Sawtooth and Coverham Groups.

1.3 PREVIOUS WORK AND TERMINOLOGY

McKay and Hector were the first geologists to visit the area, traversing from Kekerengu to Hanmer in 1885 (McKay 1886; 1890; 1892; Hector 1886). Thomson (1919) improved on McKay's stratigraphy by working in the Waima (Ure) and Clarence River catchments as far south as the middle Clarence River. King (1937a; 1937b) worked in the Kekerengu Valley, restricting his mapping to the southeast of the Kekerengu Fault. MacPherson (1948; 1952) further developed the stratigraphy of the Kekerengu River catchment. Wellman revised the type Clarenian section at Coverham (Wellman 1955; 1959). Lensen used Hall's mapping in the Coverham area to help produce his 1:250,000 geological map (Lensen 1962). Hall used his mapping as the basis of an MSc (Hall 1963; 1965): further work has supported much of Hall's mapping. The map of Gair (1967) highlights the pitfalls of spending too little time in an area of complex geology such as this, a trap which others have fallen into. Prebble mapped the Kekerengu-Waima Rivers area for his MSc (Prebble 1976) and has since published this and subsequent work (Prebble 1980). Speden (1977) re-examined some of Lensen's macrofossils from the Torlesse near Dee Stream, redating them as Clarence Series cf. Taitai Series. Mackinnon (1980; 1983) undertook a brief sedimentological surveillance in the Kekerengu River. Montague (1981) visited the area briefly during his work in the Awatere Valley. Osborne (1981) completed an MSc on the rocks southeast of the Kekerengu Fault and also made observations about the fault. University of Canterbury students have spent a few weeks mapping in the Coverham area in recent years as part of their coursework, while Victoria University students have mapped a small area in the Kekerengu River catchment.

Further up the Clarence Valley, Cretaceous stratigraphy of relevance to the study area has been developed by McKay (1886), Thomson (1919), Suggate (1958) and more recently by Reay (1980). Further unpublished and continuing work by Reay covers the Clarence Valley to within 8km of this study area. However, exact relationships between the two areas will not be confirmed until the area between has been mapped.

The previous work has been well reviewed by Hall (1965) and Prebble (1976). Tables 2.1 and 2.2 compare the various stratigraphies which have been developed.

Formation names are well entrenched in the area and seem quite workable, closely paralleling the various lithologies.

All Torlesse Supergroup-like rocks in the study area will be called 'Undifferentiated Sawtooth Group'. Good Creek Formation (Prebble 1976), Dee and Waiautoa Formations (Lensen in Suggate et. al. 1978) cannot be distinguished from each other in this area and this seems the best course until mapping is extended further south and Sawtooth Group has been formally defined. As yet the southern extent of this Group has not been established.

The use of Pikes Formation (Hall 1965) is unnecessary.

Latters, Bride and Champagne Streams are informal names used locally. Other topographic terminology follows NZMS 1 sheets S35 and S42 (1:63,360 scale).

Sedimentary rock descriptions are after Folk et. al. (1970). Abbreviations ss, zst and ms refer to sandstone, siltstone and mudstone respectively.

It should be noted that some of the stratigraphic nomenclature in this thesis has changed from that in Ritchie and Bradshaw (1985).

1.4 AIMS AND SCOPE OF THESIS

A review of the geology of the area draws attention to a number of problems.

The most striking problem is the structural and stratigraphic relationship across the Ouse Fault between the western and central blocks (*fig. 1.2*, plate 1). Problems of the relationship between the central and eastern blocks are similar but less profound. Although the Champagne, Ouse, Wharfe, Swale and Nidd formations of the western block have a similar age range to that of the Burnt Creek Formation of the central block, there are important differences (for instance in their sedimentology and thickness of Clarence Series rocks) that are maintained even when the rocks are in close proximity. The Paton Formation is the first formation common to all three blocks. A primary aim of the thesis then, is to provide an explanation for this situation.

Another problem is the nature of the controversial contact between the Sawtooth and Coverham Groups. Is there an uncomformity or is the sequence conformable through this boundary? Controversy has raged over this boundary in the Coverham area with Thomson (1919) and Gair (1967), stating that there is an unconformity, and Wellman (1955), Lensen (1962) and Hall (1965), concluding that there is not. This is in spite of an unconformity being found at the top of the Torlesse in the Awatere Valley (*fig. 1.1*) (Challis 1966), the Kekerengu River (Prebble 1976), and most other places that this boundary has been studied.

Previous workers on this boundary (Gair 1967, Hall 1965) have found no gradational contact or lithological and geochemical differences between the two sets of rocks. However, the contact separates well indurated, complexly deformed (often tightly folded) greywackes (Sawtooth) from mildly indurated, more structurally simple (open folded) rocks (Coverham Group). Therefore it seems that in structural assessment may lie the key to the demonstration of differences between the two bodies of rock. This task is another aim of the project.

A further aim of the thesis is to outline and compare the sedimentology of the Sawtooth and Coverham Groups.

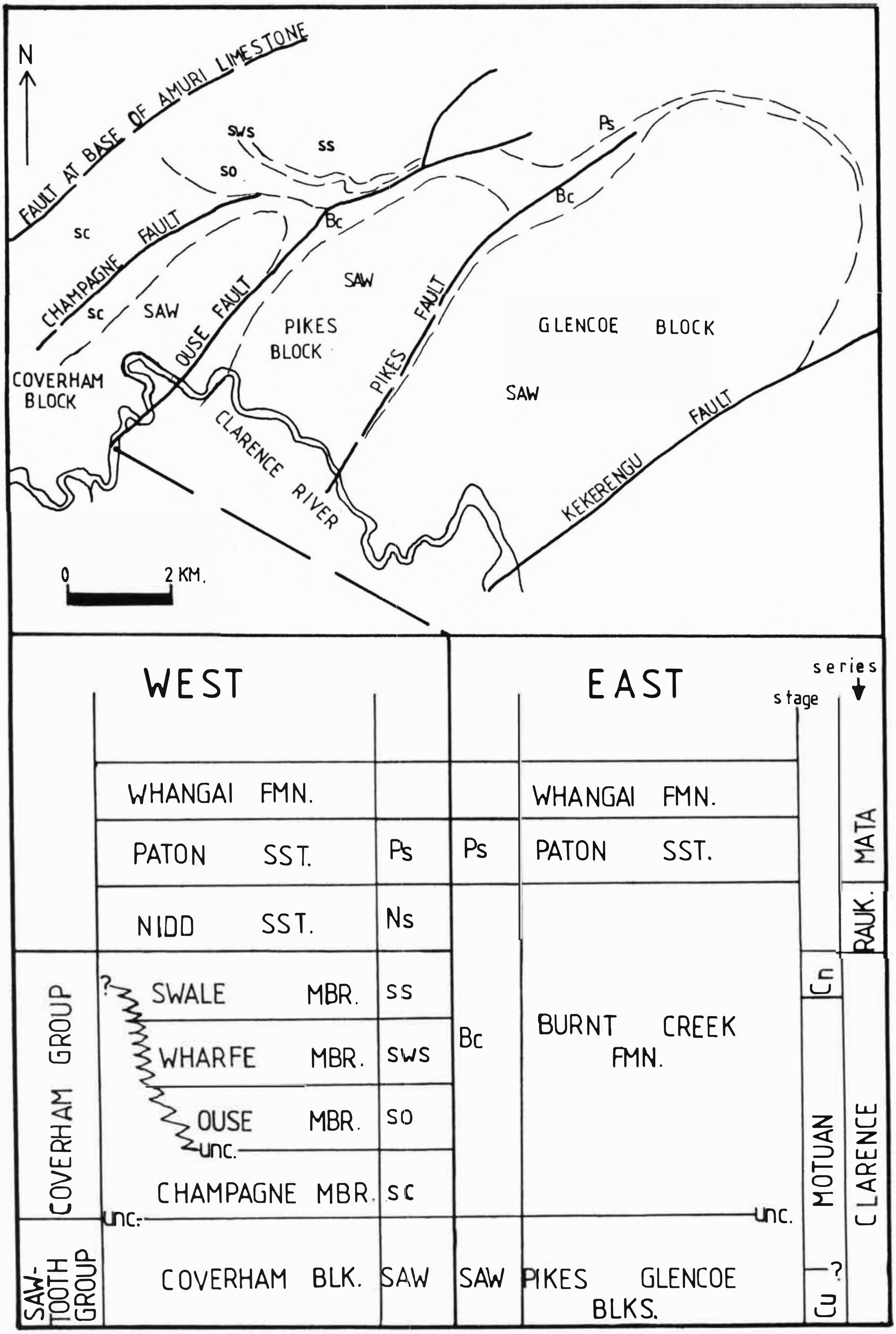


Figure 1.2 Sketch map of geology, EAST/WEST stratigraphic division and blocks.

A more general aim is to state what the 'Rangitata Orogeny' means in this area.

These problems were tackled by preparing a detailed geological map, a programme which drew attention to other topics such as the pebble composition of the numerous Sawtooth and Coverham Group conglomerates, and the type of volcanism which led to the deposition of the white tuffs found through the Sawtooth Group. In the West mapping included units up to the base of the Swale Siltstone. In the East studies did not extend beyond the top of the Burnt Creek Formation.

Seventy days were spent mapping with only five lost due to bad weather.

CHAPTER II

STRATIGRAPHY AND SEDIMENTOLOGY

2.1 INTRODUCTION

West of the Kekerengu Fault, three fault bounded slices can be recognised. The two eastern blocks show Motuan - Teratan Burnt Creek Formation resting on Sawtooth Group. The western block has a significantly different stratigraphy with Sawtooth Group overlain by thick Motuan and Ngaterian members of Split Rock Formation not seen in the eastern blocks (*fig. 1.2*).

Because of this major stratigraphic difference on either side of the Ouse Fault it is best to treat the stratigraphy on each side separately, therefore the various formations on the WEST of this fault will be described first followed by those on the EAST.

Furthermore, it is useful to identify the three slices as three separate blocks, Coverham, Pikes and Glencoe, from west to east respectively (*fig. 1.2*).

Formations subsequent to Swale Siltstone in the WEST and Burnt Creek Formation in the EAST have not been studied in any detail. Nor have the various igneous rocks found throughout the area.

Conglomerates within both the Sawtooth and Coverham Groups have received special treatment (section 2.7) because firstly they are traceable for long distances (11km+) and thus serve as excellent marker horizons. Secondly, the composition of the clasts may provide information on the geological setting at the time of deposition. White bedded tuffs are also given special attention for the latter reason (section 2.8).

WEST

2.2 SAWTOOTH GROUP

The Sawtooth Group was introduced by Lensen in Suggate et. al. (1978) for Torlesse-like rocks in Marlborough. However, neither the Group nor its three constituent formations have ever been defined or described. It is clear from Suggate et. al. 1978 (fig. 6.28, p.384) that the name was intended to apply to Cretaceous rocks which lay below the fossiliferous Motuan and younger strata of Marlborough, and it is used in this sense here. Lithological character suggests that it is a local constituent of the Torlesse Supergroup.

2.21 Coverham Block

Definition:

The base of the Sawtooth Group of the Coverham block is not exposed but is thought to be faulted.

A representative reference section for this unit can be found from G.R. 807147* in Ouse Stream, downstream to the mouth of Champagne Stream and up this stream to G.R. 790153 which is the base of the overlying Champagne Member of Split Rock Formation.

Distribution:

Sawtooth Group rocks occupy the core of the Ouse Anticline. Best exposed in Champagne Stream, the rocks also outcrop along the banks of the Clarence River, Dee and Mead Streams and a short length of Ouse Stream. Plate 1 outlines the distribution. The unit's southern limit is unknown.

It attains a minimum thickness of 1200m.

---

*Grid references are based on the national thousand-metre grid of the 1:50,000 topographical map series (NZMS 260) Sheet P30 unless another sheet is specified.

WEST		McKay 1886 and 1890	Thomson 1919	Wellman 1955	Hall 1965	this study		
Mata		Amuri Limestone members	Amuri Limestone members	Amuri Limestone members	Amuri Limestone members	Amuri Limestone members		
Raukumara		Sandstones and dark mudstones	Sawpit Gully mudstones	Whangai Shale	Whangai Shale	Whangai Shale		Coverham Group
				I. australis zone	Paton Sandstone	Paton Sandstone		
				I. A zone	Burnt Creek Formation	Nidd Sandstone		
			Nidd sandstones and mudstones	I. B zone	Nidd Sandstone			
				I. bicorrugatus zone				
Clarence	Cn	Dark micaceous mudstones	Cover Creek mudstones	I. porrectus zone	Sawpit Mudstone	Swale Siltstone Member ?	Split Rock Formation	
				I. concentricus zone				
				I. anglicus ? zone				
	Cm	Interbedded sandstones and shales	Wharfe Gorge sandstones	Wharfe Gorge Sandstone	Wharfe Sandstone	Champagne Member / **Wharfe** Sandstone Member		
		Black Shales	Wharfe mudstones	Inoceramus C. zone	Ouse Siltstone	Champagne Member / Ouse Member		
		Conglomerates	Basal conglomerates	Basal conglomerate	Pikes Formation			
		Older Secondary and Paleozoic	Pre-Notocene greywackes	Greywacke				
					Greywacke	Undifferentiated Sawtooth Group Coverham Block		

Table 2.1: Various stratigraphies developed for Sawtooth to Amuri Limestone in the vicinity of Ouse Stream. WEST portion of study area.

Note : not drawn to relative thicknesses.

Description:

In the Coverham block, Sawtooth Group comprises alternating sequences of sandstone and siltstone. In some places e.g. Champagne Stream G.R. 794152, thick sandstone up to 4m thick predominates with thin siltstone and a ss:zst ratio of about 3:1 (*fig. 2.1*). Elsewhere, e.g. Ouse Stream G.R. 803149, thin bedded sequences occur with sandstones 5 to 10cm thick and subequal siltstone. The ss:zst ratio is about 1:1. Sandstone dominated sequences may reach 200m in thickness and the more thinly bedded sequences rarely exceed 100m. The next most common lithology is massive siltstone, which is shattered and deformed and up to 50m thick. These are well displayed at G.R. 787135.

Sandstones of the thickly bedded sequences are typically non-graded. Siltstone is dark grey and unlaminated. The sandstones of the thin bedded units are graded. Some sandstones show Bouma sequences AD (Bouma 1962), however these were probably once laminated and convoluted but this has been masked by later deformation. Bouma ACD is found in Champagne Stream.

The sandstone beds are boudinaged and losenged partly by soft sediment deformation and partly by subsequent faulting and folding (*fig. 2.1*). In some places e.g. Mead Stream (G.R. 760131), paraconglomerate occurs. Isolated sandstone clasts and 'bed chunks' (see Abbate et. al. 1970) are found in a muddy matrix. These could be either endolistostromes in the sense used by Elter and Raggi (1965) and Abbate et. al. (1970) p.522, 525; endo - meaning they consist of material derived from the same sequence in which the olistostrome is enclosed; or the rocks have undergone such a high degree of tectonic deformation that they now have the appearance of a paraconglomerate. I favour the former interpretation i.e. olistostromes travelling between 100's of metres and kilometres within the Sawtooth Group. Whichever mechanism formed these paraconglomerates, it occurred immediately after the beds were laid down and when the sediments

Figure 2.1 Undifferentiated Sawtooth Group, Coverham Block, Champagne Stream (true right) (G.R. 797153). Alternating sandstone and siltstone. Ss:zst ratio = 3:1. Boudinaged sandstone beds, facing to right.

were supersaturated with water. Sandstone dikes cut through sandstone beds in Mead Stream. Some of these dikes appear to have injected simultaneously with a minor syn-sedimentary phase of faulting and also occurred immediately after deposition with excess water around.

Beds of white tuff up to 2m thick occur occasionally throughout the Sawtooth.

Below is a list of lithofacies present with relative percentages of each.

$<$0.05% L_3 = tuff

c. 25% L_2 = massive siltstone

c. 75% L_1 = cm-dm-m* bedded flysch-like alternating sandstone/siltstone

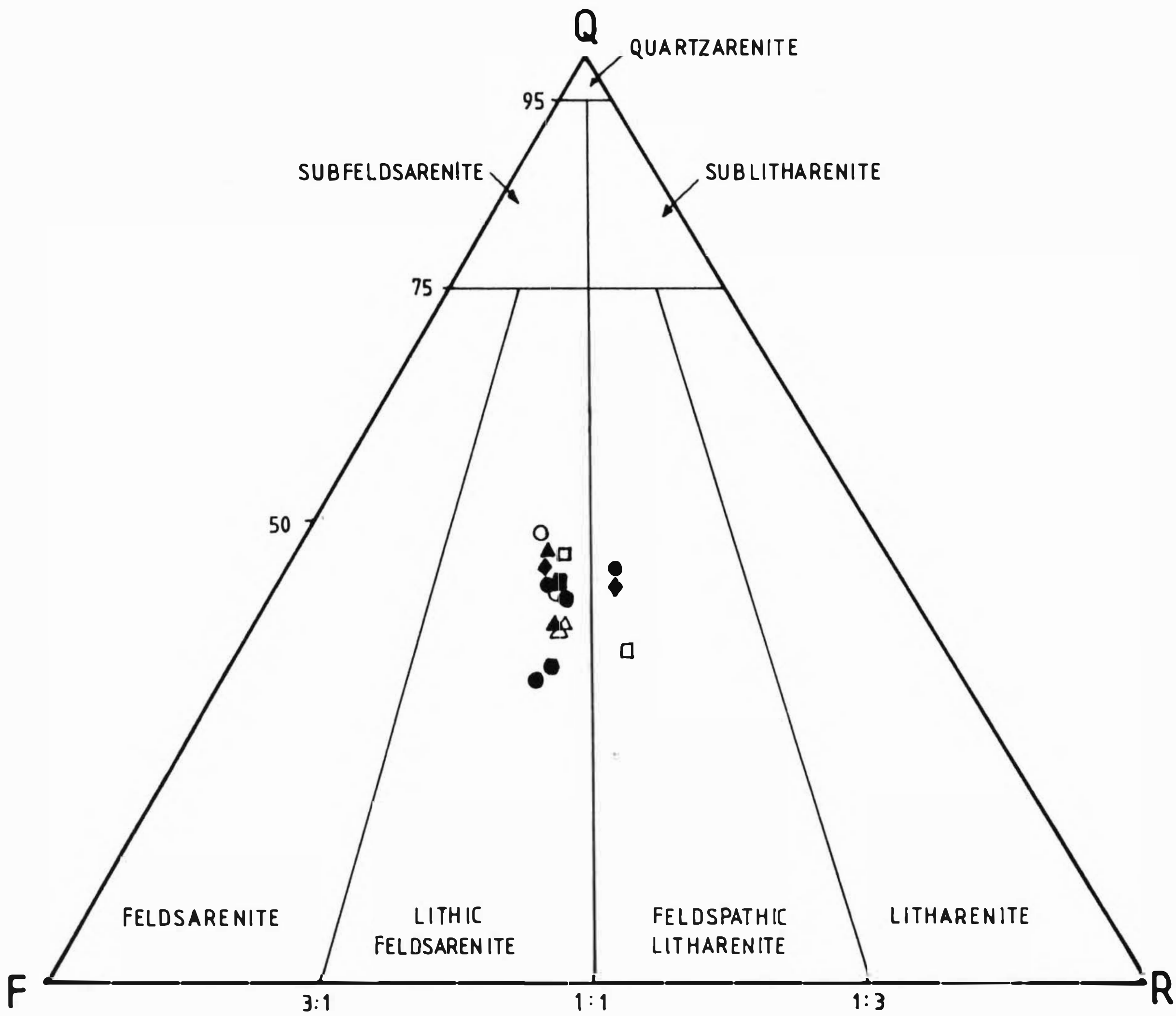
Sandstone is typically fine-medium grained and poorly sorted (lithic feldsarenite (*fig. 2.2*)). The siltstone is well sorted and often graded. Full hand-specimen descriptions appear in Appendix I(a).

A typical sandstone e.g. C.U. 10601•, contains 27% quartz, 22% plagioclase, 20% lithic fragments, 4% potassium feldspar and minor amounts of detrital mica, calcite (*Inoceramus* fragments), heavy minerals, and opaques in a fine grained matrix of quartz, feldspar and clay minerals. Calcite veining and cementation is common. Full petrographic descriptions are found in Appendix I(a). A selection of thin-sections of sandstones from all formations were stained for plagioclase and potassium feldspar. The compositions are plotted in *fig. 2.2* and the raw data appears in Appendix I(b).

---

*cm, dm, m : abbreviations for centimetre, decimetre and metre respectively.

•Refers to University of Canterbury rock sample catalogue numbers.



◆ Burnt Creek Formation
▲ Wharfe Member
■ Ouse Member
● Champagne Member

○ Sawtooth Glencoe Block
□ Sawtooth Pikes Block
△ Sawtooth Coverham Block

Figure 2.2 QFR diagram of sandstone samples from all formations. (after Folk et.al. 1970). Refer to Appendix 1(b) for data.

Age:

Although not dated within the study area very similar rocks to the southwest near the mouth of Dee Stream are probably Urutawan - Motuan in age (see Speden 1977, p.550). The dates are based on re-identification of a collection made by Lensen thought by him to be Taitai series. Speden identified *Inoceramus sp. ex. gr. kapuus - ipuanus* (Fossil Record File No.* S42/f582 (G.R. 070387)).

Interpretation:

Lack of extensive bioturbation, cross-bedding, and other energy indicators, and presence of only minor plant material and rare broken fossils, suggests deposition below wave base in a low energy environment. The Sawtooth was deposited by periodic sediment gravity flows probably in a submarine fan setting. Andesitic-rhyolitic volcanism was contemporaneous with deposition. Failure occurred periodically on the depositional slope.

---

*Henceforth abbreviated to F.R.F.

2.3 COVERHAM GROUP

The Coverham Group (Lensen in Suggate et. al. 1978) is extended down to include a new unit, the Champagne Member of the Split Rock Formation. The Group comprises thick Motuan - Ngaterian clastic sediments in the Coverham block.

2.31 Split Rock Formation (Suggate 1958)

The Split Rock Formation was introduced for alternating sandstone and mudstone in Split Rock Stream in the middle Clarence Valley (Suggate 1958 p.400). Reay (1980) divided the formation into three members and has since traced the formation northeast 35km down the Clarence Valley as far as Whiskey Stream (Sheet O30/G.R. 699073) (Reay - pers. comm.). It is proposed to extend the name Split Rock Formation to the Coverham area for alternating sandstone and mudstone rocks of Motuan age which bear strong similarity to those at the type section. Four new members: Champagne, Ouse, Wharfe Sandstone and Swale Siltstone are recognised.

2.32 Champagne Member sc (new unit)

Definition:

Champagne Member is introduced for predominately alternating sandstone and mudstone parts of Split Rock Formation. It is widely developed in the lower part of the Formation and forms the bulk of the unit near Mead Stream. However, in the Ouse-Wharfe area it is laterally replaced by the Ouse sequence and Wharfe sandstone. Age is Motuan - Ngaterian.

Part of the Champagne Member was previously included in Pikes Formation by Hall (1965). However Hall included other unrelated rocks in Pikes Formation and this name should be allowed to lapse to avoid confusion. Workers previous to Hall have generally regarded the Champagne Member as Torlesse greywacke (Table 2.1) and have mistakenly described the contact between Champagne and Ouse Members at the upstream end of Ouse Gorge

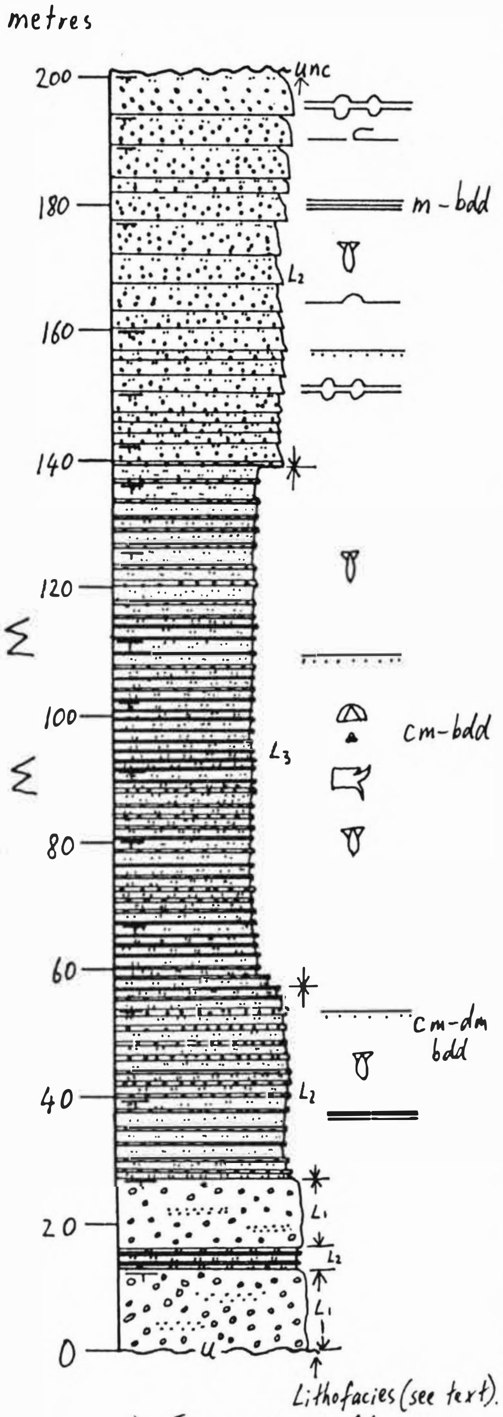
(G.R. 817164) as the Torlesse/non-Torlesse boundary. Detailed mapping the this vicinity in fact shows the basal contact to be at the base of the Champagne Member i.e. 1km further down Ouse Stream at G.R. 812156 (Plate 1).

The base forms an angular unconformity with Sawtooth Group in some places e.g. Mead Stream (G.R. 770132). Elsewhere, the bedding of the two units is sub-parallel, subsequent deformation is intense, and the contact is thought to be a paraconformity e.g. Ouse Stream (G.R. 812156). This difference in the nature of the contact is thought to be due to growth and subsequent erosion of the Ouse Anticline contemporaneous with Champagne Member deposition (see Chapter III).

A detailed measured stratigraphic section of 200m thickness through the lower part of this member in Ouse Stream presented in *figure 2.3* is a fair representation of the unit.

Distribution:

The Champagne Member wraps around the Ouse Anticline (Plate 1). On the eastern limb it outcrops in the upper part of Ouse Stream for 2km downstream from the junction of Ouse, Bride and Latter's Streams (from G.R. 817164 to G.R. 807147). The thick conglomerate several hundred metres down Ouse Stream from its junction with Champagne Stream (at G.R. 802146) is also interpreted as the basal conglomerate of the Champagne Member. Further to the southwest this conglomerate outcrops on the banks of the Clarence River (Plate 1). On the western limb, the Champagne Member including the basal conglomerate, is found in Dee, Limburn (both branches), and Mead Streams (Plate 1). In Mead Stream the rocks extend upstream to the fault contact with Amuri Limestone (G.R. 765161). Further northeast it outcrops in champagne Stream and its tributaries and extends as far as Swale Stream.



TOP- Disconformity with Ouse Member.

Sandstone and Siltstone: 43m. Interbedded ss/zst; m bdd., moderately hard, light grey, slightly weathered, graded bedding, sst beds often with gritty bases, mud-chip breccia, flame structures, sand injection structures, convoluted bedding, ss. often boudinaged, intense mesoscopic faulting.

Sandstone and Siltstone: 86m. Interbedded ss/zst; cm bdd, ss moderately hard, well graded; siltstone moderately soft, dark grey, shattered, occasional <u>Inoceramus</u>, volcanic dikes and sills, calcareous ss. lenses; mesoscopic folding, intensely normal faulted: Beds are losenged and deformed : broken formation.

Sandstone and Siltstone: 31m. Moderately hard, well graded; cm-dm bdd; ss. beds thinning upwards.

Conglomerate: 27m. Interbedded with dm-m bdd. ss; matrix supported crs. pbb. conglomerate. Clasts predom. ss - also volcanic igneous. 2 beds of cgl. sep. by 3m flysch.
BASE - Disconformity with Sawtooth Group.

Figure 2.3: Measured Stratigraphic Section of Champagne Member of Split Rock Formation, Ouse Stream. G.R. 812 156 (base) to G.R. 817164 (top). see also C.C.P. Measured Section Detail Sheet (Appendix III). [see graphic symbols key, page 172].

The unit attains a minimum thickness of 1260m.

Description:

The Champagne Member comprises alternating flysch-like sequences of sandstone and siltstone. In some places (e.g. Ouse Stream, G.R. 817164) thick sandstone up to 1m thick predominates with thin siltstone and a ss:zst ratio of 8:1 (*fig. 2.6*). Nearby (e.g. Ouse Stream, G.R. 816162) siltstone rich thin bedded sequences occur with sandstones 5-15cm thick and siltstones 5-20cm thick. Here the ss:zst ratio is 1:1 - 1:2. Elsewhere, (e.g. Mead Stream, G.R. 771143) sandstones are up to 1m thick and siltstones up to 2m thick and have a ss:zst ratio of 1:5 (*fig. 2.4*). Sandstone dominated sequences reach 40m in thickness but siltstone dominated sequences predominate reaching thicknesses of 400m+. Sandstones within the sequence show a generally thickening upward tendency.

Sandstone dominated sequences are typically poorly graded, parallel laminated and show partial Bouma sequences ABCD, and BCD. Amalgamation of two or more ABC sequences is common. The sandstones of the siltstone dominated units are graded, commonly show strong parallel lamination and Bouma sequences BCD and BD.

Sandstone and siltstone dikes, mud-filled micro-faults and pull-apart structures, losenged and boudinaged sandstones are widespread and especially well exposed in Ouse Stream gorge (G.R. 817164) *figs. 2.6, 2.7, 2.8*. Here the syn-sedimentary and tectonic deformation has been so intensive that the unit ranges from a disrupted bedded sequence to a 'broken formation', with sheared sandstone beds showing a high degree of disruption yet still maintaining gross parallelism (*fig. 2.7*). Some workers would go as far as to call these rocks mélange. Cowan (1985) describes four different types of mélange in the Fransiscan rocks of California. The rocks here in the Ouse Gorge would fit into his 'Type 1' mélange, however I would prefer to

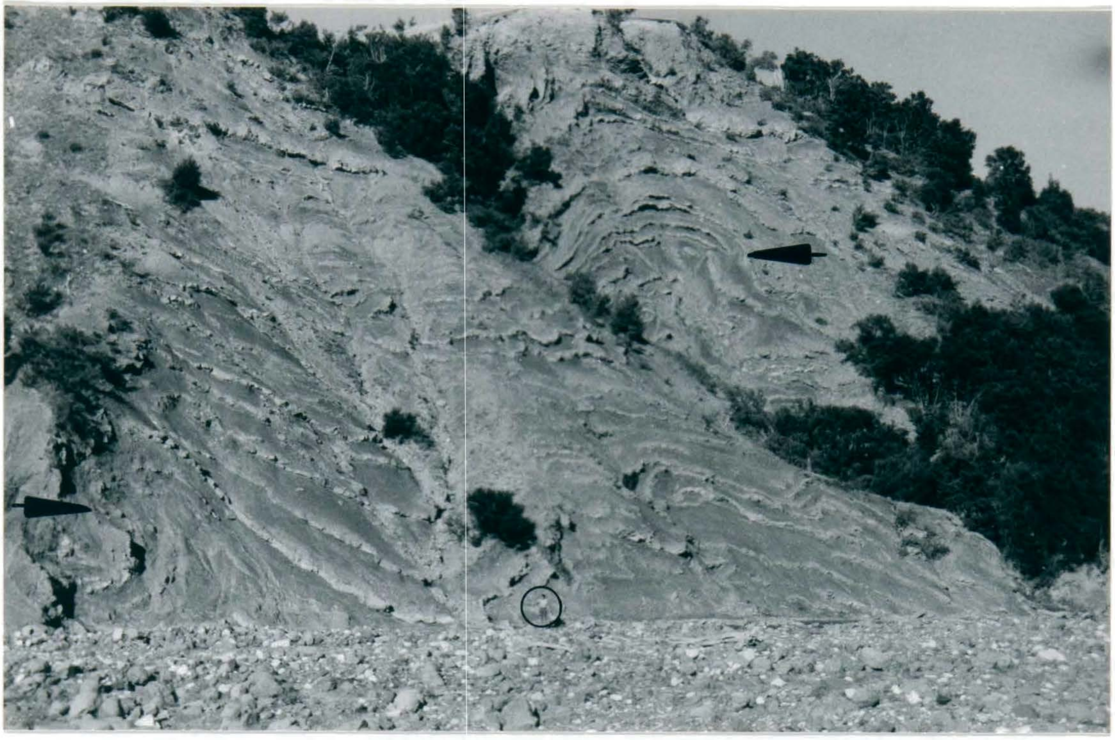


Figure 2.4 Champagne Member of Split Rock Formation, Mead Stream (true left) (G.R. 771143). Complexly folded alternating sandstone and siltstone. Ss:zst ratio = 1:5. Box-shaped folds arrowed. Person for scale circled.

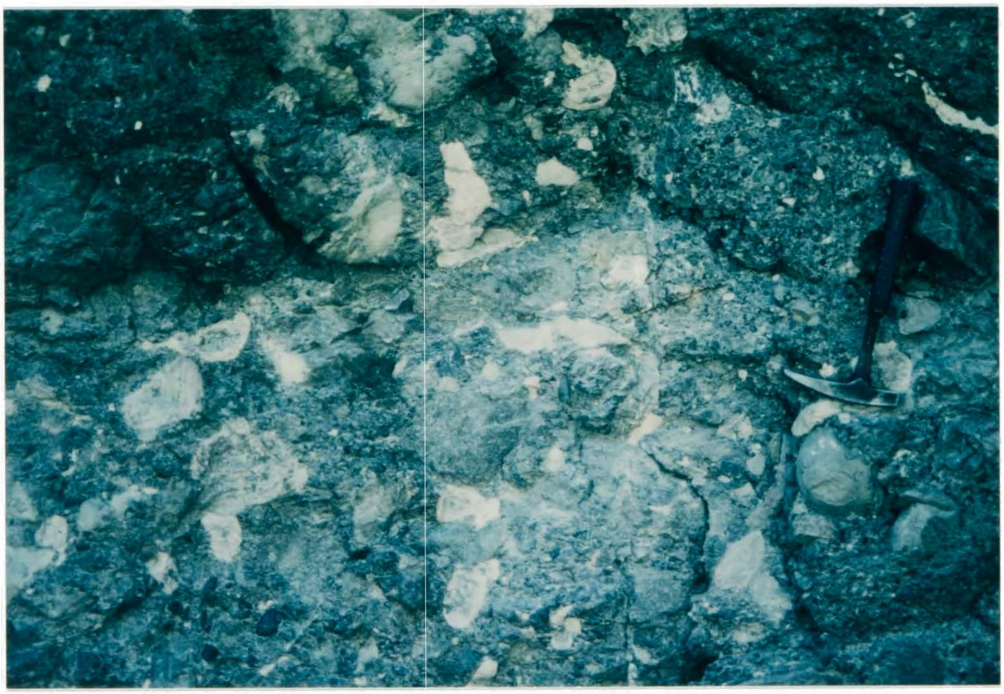


Figure 2.5 Basal part of basal conglomerate of Champagne Member, Split Rock Formation, Ouse Stream (true left) (G.R. 802146). BB conglomerate. Angular white tuffaceous clasts obvious. Hammer is 33cm long.

Figure 2.6 Thick m-bedded sandstone alternating with siltstone, Champagne Member, Split Rock Formation, Ouse Stream (true right) (G.R. 817164). Ss:zst ratio = 8:1. Thick sandstones at entrance to Ouse Gorge. Person for scale.

Figure 2.7 Highly deformed interbedded sandstone and siltstone of 'broken formation', Champagne Member, Split Rock Formation, Ouse Stream (true left) (G.R. 816162). Tape for scale.

Figure 2.8 'Broken Formation' of Champagne Member, Split Rock Formation, Ouse Stream (true right) (G.R. 816162). Intense deformation - faulting and folding.

use 'broken formation' in the sense of Hsü (1968) because; 1. in the literature there seems to be quite an overlap between the two terms; 2. mélange has an entrenched inference of containing exotic clasts e.g. blueschist, volcanics etc.; 3. this area does not perhaps show the whole spectrum of Type 1 mélange (see Cowan 1985, *fig. 3*, p.453); i.e. does not have the most deformed rocks of the spectrum. Layer parallel extension while unlithified is favoured as the origin. These beds do not look like olistostromes. Large scale gravity induced slumping forming layer parallel extension cannot be completely ruled out but extension of beds around the proven anticline (Plate 1) is most likely (see Chapter III, p. 98 for further discussion).

The basal conglomerate (*fig. 2.5*) which is 15-25cm+ thick can be traced for 11km around the Ouse Anticline and forms two 10m thick beds separated by up to 15m of flysch. Descriptions and analyses of this conglomerate are found in section 2.7. Massive lensoid sandstones up to 15m thick occur in Champagne Stream. A single bed of white tuff outcrops in the upper reaches of Champagne Stream (G.R. 792165). Below is a full list of lithofacies:

L_5 = tuff

L_4 = massive sandstone

L_3 = cm-dm bedded flysch-like alternating ss/zst: siltstone dominant

L_2 = dm-m bedded flysch-like alternating ss/zst: sandstone dominant

L_1 = conglomerate

Thicknesses of lithofacies L_1-L_3 and further detailed descriptions are presented in *figure 2.3*. Lithofacies L_4 and L_5 occur only in the upper part of the Champagne Member.

Sandstones are typically medium grained, poorly sorted sands : lithic feldsarenite. One centimetre thick lenses of coal (e.g. Mead Stream, G.R. 769155) and carbonaceous material are widespread in the sandstones. A typical Champagne Member sandstone (e.g. C.U. 10597) comprises 30% quartz, 15% plagioclase, 8% potassium feldspar, 24% lithic fragments, 2% detrital mica, and 3% opaques etc. They are often calcite cemented and fossiliferous with up to 0.5% shell fragments. *Figure 2.2* plots Q.F.R. data for these sandstones and full petrographic data is presented in Appendix I(a).

Parts of this Member have been described in the section on 'Pikes Formation' by Hall (1965).

Paleontology and Age:

Dating of the Champagne Member has been primarily on microflora with moderate to rich yields of miospores and dinoflagellates. Full species lists are reproduced in Appendix II. Echinoid plates and spines and foraminifera have been found only by thin-sectioning from sample C.U. 10581 in Ouse Stream. *Inoceramus sp. ex. gr. ipuanus - kapuus* is common in the lower part of the member, e.g. in Ouse Stream. 'Chondrites'-like trace fossils are also found in Ouse Stream.

These collections indicate a Urutawan - Ngaterian age for the Champagne Member. The outcrop in Ouse Stream is of the lower part of the member and is Urutawan - Motuan. The Ngaterian dates are found higher up in the sequence e.g. near trig S.T.6, F.R.F. No. P30/f252.

Fossil localities appear on Plate 1.

2.33 Ouse Member so (new unit)

Definition:

Ouse Member is a new name which has developed from Ouse Siltstone (Hall 1965) and a variety of previous names.

The base of the member forms a disconformity with a lower part of the Champagne Member (Plate 1).

Hall described the Ouse Member in detail as well as providing a type section (Hall 1965, p.17). This type section in Ouse Stream between the contact with the Champagne Member and the base of the Wharfe Sandstone Member is retained. A more detailed measured stratigraphic column of this same section is provided in *fig. 2.9*.

Distribution:

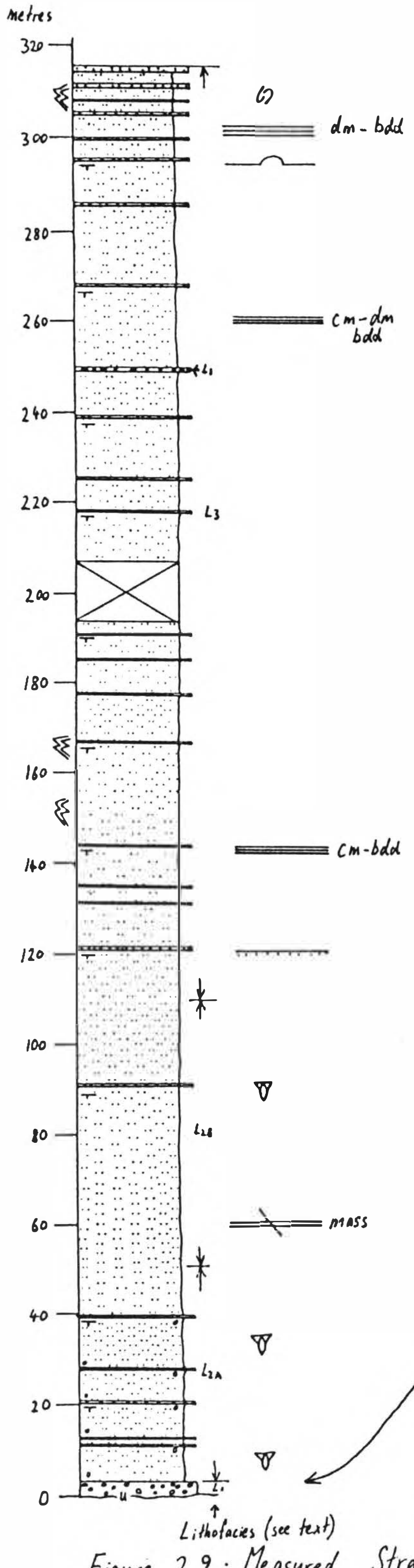
Ouse Member is only developed locally. Hundreds of metres of superb exposure is found on the banks of Ouse Stream and Bride Stream and its tributaries. It is less extensively developed in Swale Stream where it is only tens of metres thick.

Thickness of the unit in Ouse Stream (see measured section *fig. 2.9*) is 315 metres and it may be up to 500m thick in the upper reaches of Bride Stream.

Description:

The Ouse Member comprises massive siltstones and alternating flysch-like sequences of sandstone and siltstone.

Three lithofacies can be recognised and are best described from Ouse Stream. The basal conglomerate is only developed locally and is 2-3m thick (*fig. 2.10*). The lithology is repeated up-section (*fig. 2.9)*. Overlying the conglomerate is a 47m thick *Inoceramus* shellbed with a siltstone matrix and occasional graded sandstone beds which often have granular bases (*fig. 2.11*).



TOP - Gradational contact with Wharfe Sandstone Member.

↑ Sandstones gradually thickening as contact approached.

Deformation in the top 30m; mesoscopic steeply plunging folds.

Sandstone and Siltstone: (cont.). Siltstone as below; sandstone cm-dm bdd, gradually thickening up-section; noticable thickening immediately above Conglomerate; Convoluted bedding; normal faulting.

Conglomerate: 2m. locally derived.

not exposed.

Sandstone and Siltstone: 206m. Interbedded; Sandstone: cm-bdd, up to 20cm thick, graded, calcareous cemented. Inoceramus; Aucellina on bed bases; massive siltstone becoming more sandy up-section; glauconitic.

Deformation; faulting and folding, highly fossiliferous - Inoceramus.

Siltstone: 50m. massive, shattered and crumbly siltstone with scattered Inoceramus; alternating layers of siltstone with Inoceramus and siltstone without Inoceramus (m-scale); white calcite veining; very strong cleavage at 035/090.

Siltstone: 47m. Moderately hard, dark grey, slightly weathered, crumbly, with Inoceramus shell-bed; cm-bdd; ss beds well graded; medium-coarse sandstone; occasional pebbles; intense normal faulting.

Conglomerate: 3m. Moderately hard, light grey, slightly weathered, well rounded to angular, clast supported, coarse pebble conglomerate with sandstone matrix; occurs only locally at base of Ouse Mbr; Clasts: 99% locally derived ss + zst, <1% igneous volcanics; rare ss boulders, carbonaceous rip-up ss. beds containing Inoceramus frags.

BASE - Disconformable with m-bd. sandstones of Champagne Member.

Figure 2.9: Measured Stratigraphic Section of Ouse Member of Split Rock Formation, Ouse Stream. G.R. 817 164 (base) to G.R. 823169 (top). - see also C.C.P. Measured Section Detail Sheet (Appendix III). [See graphic symbols key, page 172].

Figure 2.10 Basal conglomerate of Ouse Member, Split Rock Formation, Ouse Stream (true left) (G.R. 817164). Predominately sandstone and siltstone clasts. Hammer is 33cm long.

Figure 2.11 *Inoceramus* shellbed in siltstone lithology. Beds of shell fragments defining strike. Ouse Member, Split Rock Formation, Ouse Stream (true right) (G.R. 817165). Compass is 7.5cm wide.

This passes up into massive siltstone with rare cm-bedded sandstone beds. This lithofacies is 50m thick and alternates between ≈5m thick horizons of siltstone with *Inoceramus* and siltstone without *Inoceramus*. The uppermost lithology is a 206m upward thickening sequence of flysch-like sandstone and siltstone (*fig. 2.12*).

The member as a whole is upward thickening. Ss:zst ratios vary from almost totally siltstone dominated in the massive siltstones to ratios of 1:7 in the uppermost lithofacies. Bouma BCE and CE with BC being amalgamated two or three times, are present in the graded sandstones in the upper part of the sequence. In the occasional sandstones in the lower part of the member BE sequences are most common.

Mesoscopic syn-sedimentary slumps are exposed in Ouse Stream near the top of the formation (G.R. 823168), and to a minor extent lower in the formation. Syn-sedimentary faulting is responsible for sandstone deformation in lower parts of the formation (*fig. 2.12*). Sole markings are developed in the upper sandstones.

Below is a full list of lithofacies:

L_3 = cm-dm bedded flysch-like alternating sandstone and siltstone

L_2 = subfacies B : massive siltstone with rare graded cm sandstone beds

subfacies A : massive siltstone with *Inoceramus* shellbed

L_1 = conglomerate

Their various thicknesses appear on the measured section (*fig. 2.9*).

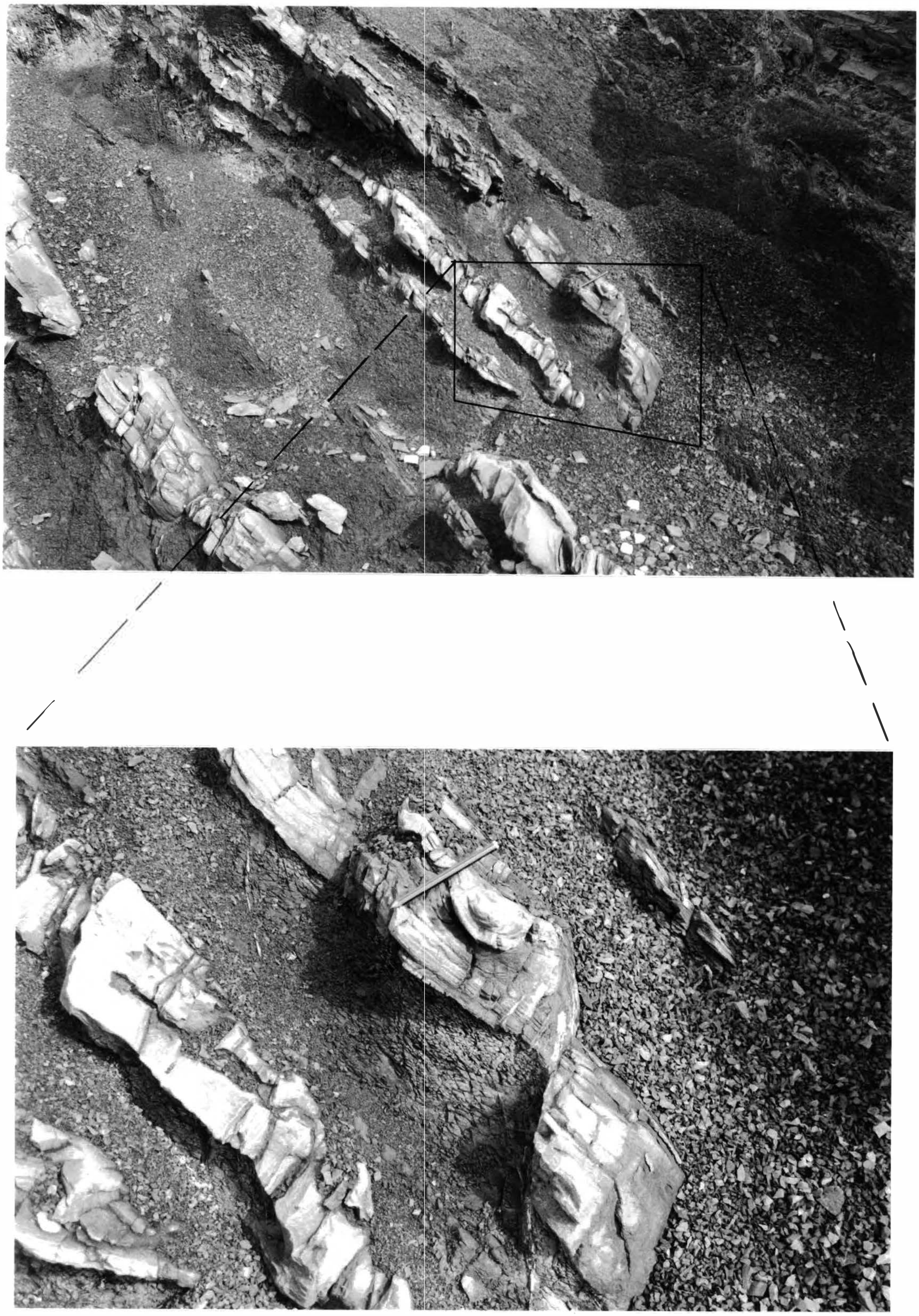


Figure 2.12 Uppermost lithology of Ouse Member, Split Rock Formation, Bride Stream (G.R. 804167). Alternating sandstone and siltstone with convoluted beds. Normal fault pattern evident. Pencil for scale is 16 cm long.

Conglomerate of the basal lithology is locally derived, light grey and clast supported with a coarse pebble grain-size and a sandstone matrix (*fig. 2.10*). Further description and analysis of its clast composition is presented in section 2.7. Sandstones of the member as a whole are typically well sorted and graded lithic feldsarenites. Siltstones are dark grey, well bedded and fissile. Coalified wood is found rarely throughout this member.

Petrographically, the sandstones are composed of 26% quartz, 19% plagioclase, 3% potassium feldspar, 13% lithic fragments, 0.6% detrital mica, 8.3% opaques, calcite, and a wide selection of heavy minerals (D. Smale - pers. comm.). Appendix I(a) provides hand-specimen and petrographic descriptions and the sandstone is plotted on a Q.F.R. diagram (*fig. 2.2*).

Paleontology and Age:

The fauna of the Ouse Member in Ouse Stream has been collected over a long period of time by a large number of geologists. There is also good microfloral control. Key fossils include:

Inoceramus ipuanus Wellman
Inoceramus urius Wellman
Aucellina euglypha Woods

Foraminifera and rare ammonites have also been collected. A polymorphinid benthonic foraminifera has been recognised in thin-section.

Age is well documented as Motuan.

2.34 Wharfe Sandstone Member sws (new unit)

Definition:

Geologists since Thomson (1919) have recognised the distinctiveness of this unit which takes its name from Wharfe Stream (Table 2.1).

The base of the member exhibits a gradational contact with the Ouse Member.

Wharfe Stream gorge (G.R. 826168) was suggested as the type section by Hall (1965) but he does not describe the sequence. Instead he makes a number of general observations about the member (Hall 1965, p.20). This is the best place for a type section and is illustrated and described in *figure 2.13*.

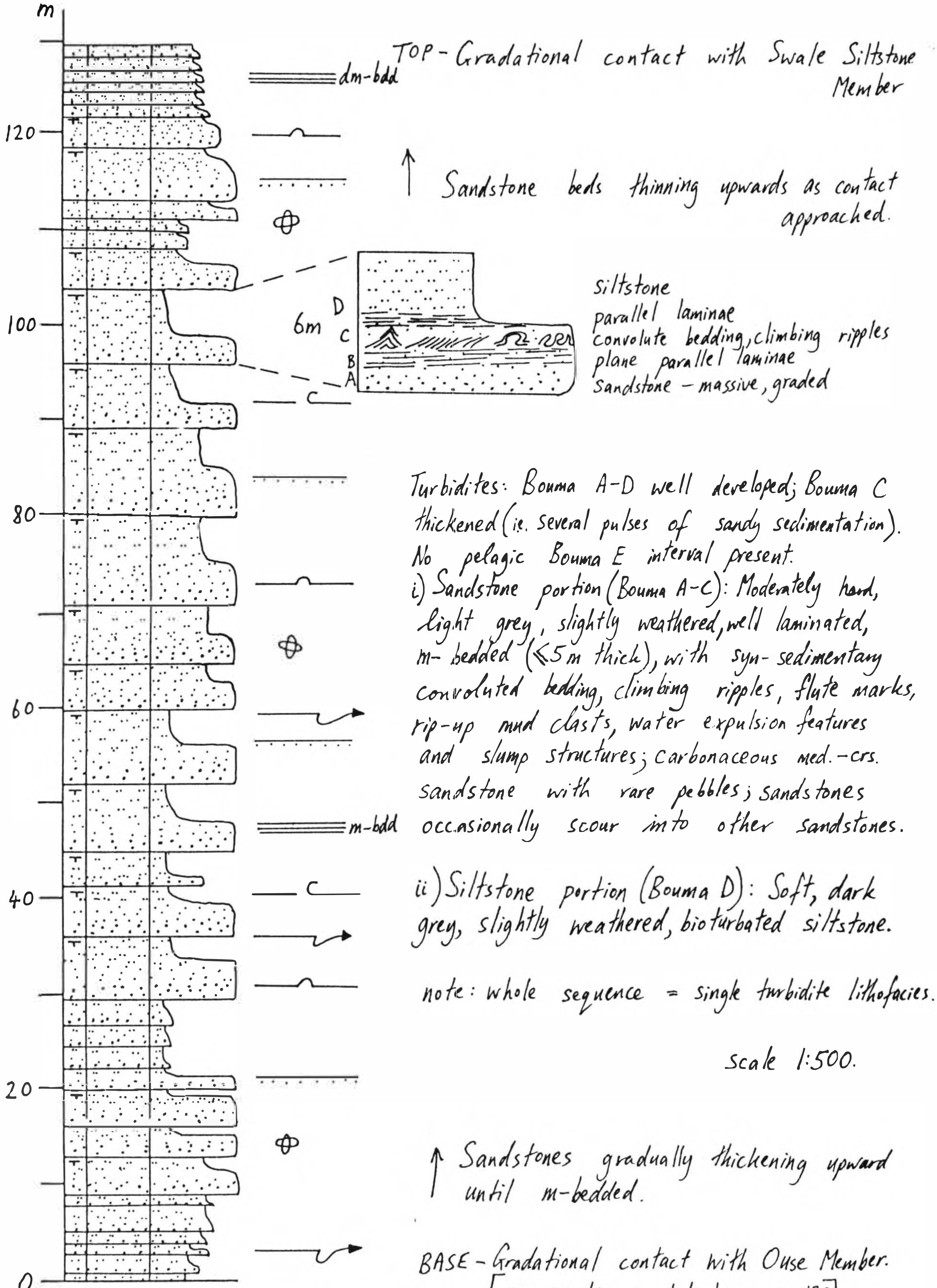
Distribution:

The resistant sandstones of the Wharfe Sandstone form a strike ridge which extends from southwest of Swale Stream, east to the north side of Wharfe Stream upstream from the gorge (Plate 1). Fresh outcrop occurs where it crosses Ouse and Swale Streams (G.R. 823170) but the best exposure is in Wharfe Stream gorge (G.R. 826168) where the member is at its thickest (*fig. 2.14*).

It attains a maximum thickness of 128m in Wharfe Stream gorge.

Description:

The Wharfe Sandstone comprises alternating sandstone and mudstone of a single turbidite-like lithofacies. Thick (0.5-6m) Bouma A-D sequences are well developed with thinner (5-20cm) Bouma AD between (*fig. 2.14*). The absence of Bouma E may be due to rapid sedimentation leaving no time for pelagic deposition. In the thicker sandstones 3 or 4



[see graphic symbols key, page 172]

Figure 2.13: Measured stratigraphic section of Wharfe Sandstone Member; Wharfe Stream Gorge. - see also C.C.P. Measured Section Detail Sheet (Appendix III)

amalgamations of Bouma AB are common representing pulses of sandy sedimentation. The thinner sequences are often developed 4 or 5 times between the more complete Bouma sequences. The sequence generally thickens upwards but near the top of the member thins rapidly. The ss:ms ratio is approximately 1:1.

Certain layers within the sandstones contain carbonaceous debris with plant fragments and 1cm thick coal lenses developed. Bioturbation by unknown species forming narrow burrows is common in Bouma D. In places the sandstones channel into the beds beneath.

Syn-sedimentary structures are numerous and include flute casts, wavy lamination, convoluted bedding, slumping, sandstone dikes and flame structures (*figs. 2.15, 2.16, 2.17*). The nature of some of these structures suggests that the sediments were super-saturated with water when they were emplaced.

In comparison with the thick sandstones of Champagne Member, Wharfe sandstones have a higher degree of soft sediment deformation, they are less disrupted by faulting, and do not show boudinage and losenge structures. Some of the faulting appears to be penecontemporaneous with deposition.

The sandstone is typically very fine - medium grained, moderately well sorted sandstone: lithic feldsarenite. A typical sandstone (C.U. 10604) contains 27% quartz, 21% plagioclase, 5% potassium feldspar, 18% lithic rock fragments, 0.6% detrital mica, 7% opaques and a large assortment of heavy minerals (D. Smale pers. comm.). Calcite cementation is common. Full petrographic descriptions are found in Appendix I(a).

Figure 2.14 Well bedded alternating sandstone and siltstone of Wharfe Member, Split Rock Formation, Wharfe Stream (true left) (G.R. 827167). Dog for scale is labrador.

Figure 2.15 Flute casts on base of sandstone beds of Wharfe Member, Split Rock Formation, Wharfe Stream. Hammer handle is 19cm long.

Figure 2.16 Sandstone dikes, water injection and slump structures, Wharfe Member, Split Rock Formation, Wharfe Stream (G.R. 827167). Hammer and pencil for scale, 33cm and 14cm long respectively.

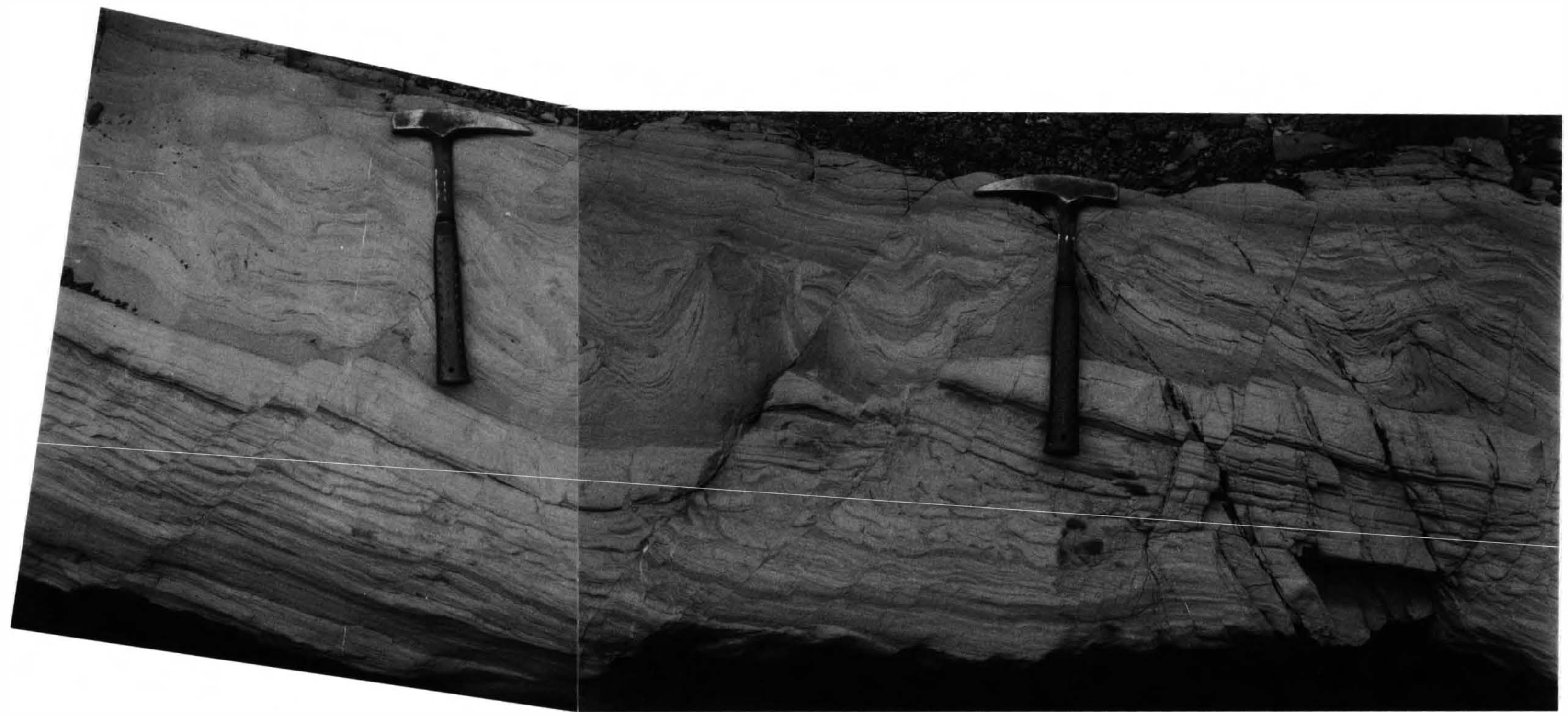


Figure 2.17 Typical sandstone bed of Wharfe Member, Split Rock Formation, Wharfe Stream. Bouma sequence A-D well developed. Hammer for scale is 33cm long.

Figure 2.13 provides further description of the formation.

Paleontology and Age:

Aucellina euglypha collected by Hall and microfloral assemblages collected by J.I. Raine and P. Oliver indicate a Motuan age.

2.35 Swale Siltstone Member ssw (new unit)

The Swale Siltstone is tentatively included in the Split Rock Formation because it is in part contemporaneous with the Ngaterian Champagne Member at G.R. 788174 (F.R.F. No. P30/f252). However it is much less sandy than the other parts of the Split Rock Formation and may be given formation status if it can be traced on a regional scale.

The unit has previously been given a variety of names (Table 2.1). The base of the member forms a gradational contact with Wharfe Sandstone Member. Hall provides a standard section and describes the unit (Hall 1965, p.22). Best exposure is on the banks of Swale Stream for 2km upstream from its mouth, and on the road up to Coverham from Swale Stream. The member essentially consists of monotonous massive siltstone with rare sandstone beds and lensoid and spherical sandstone concretions which are often calcareous and contain *Inoceramus* (*fig. 2.18*). These form along bedding planes. Age is largely Ngaterian.

Figure 2.18 Swale Siltstone Member of Split Rock Formation, Cover Stream (G.R. 829176). Massive to thin bedded siltstone with sandstone concretions and occasional sandstone beds. Face is c.30m high.

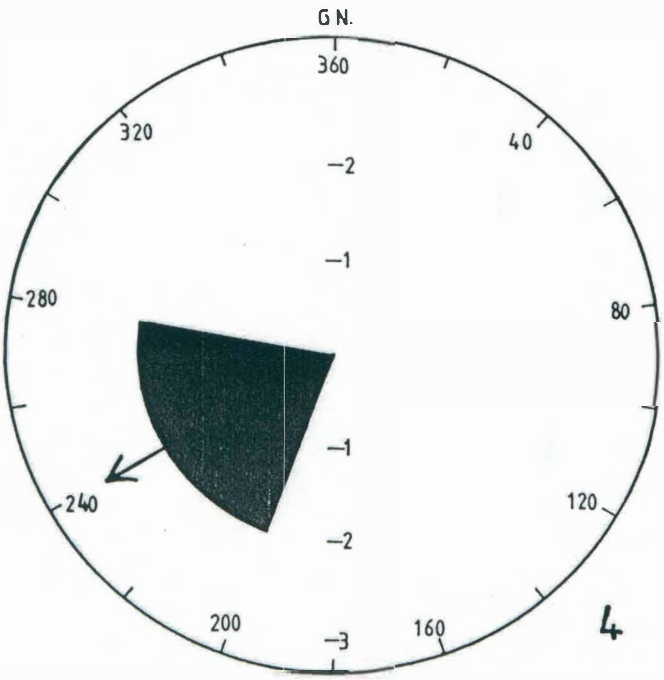


Figure 2.19 Rose diagram of current indication data (flute casts) in Wharfe Sandstone Member (4 readings). Arrow indicates dominant direction of current flow. Increments equal 1 reading. Segments = 40°.

2.36 Depositional Setting of Split Rock Formation

Overall character of these rocks which display no large cross-bedding, contain only minor plant material, are poorly sorted, often have only localised distribution, and are dominated by flysch, suggests they formed in a low energy environment below wave base in restricted basins. Presence of echinoids and calcareous foraminifera suggest only moderate depths. The basal conglomerate of the Champagne Member is likely to have been emplaced by debris flows and to have its source from erosion of other Sawtooth or Sawtooth-like rocks. The upper part of Champagne Member is laterally equivalent to Ouse, Wharfe and Swale Members suggesting rapid facies change and small scale sedimentary environments with local control. Ouse, Wharfe and at least the lower part of Swale Members were deposited by mass-flow processes in a small, restricted sub-basin on top of the deformed lower part of Champagne Member. This created a local disconformity. Wharfe Sandstone is thought to have been deposited by sediment gravity flows in a small fan lobe on top of the Ouse Member. The lower part of Swale Member was deposited on top of Wharfe Member in the same sub-basin but the upper part of it is thought to be more extensive and may be correlative with fine grained Ngaterian beds reported in the Awatere (Laird and Lewis 1980, p.B13-B15). Current direction indicators (flutes) in the main body of Wharfe Member suggest a transport direction from what is now the east northeast (*fig. 2.19*). Structural interpretation implies than an extensional tectonic regime was operative during the deposition of the beds (see Chapter III, also Laird 1980).

The most likely depositional environment for the Split Rock Formation in the Coverham region is in a slope basin environment. Ouse, Wharfe and Swale Members were deposited in a sub-basin on this slope with other Wharfe-like sediment being introduced intermittently along the basin. Deposition in a slope environment similar to that described by Underwood and Bachman (1982, fig. 5, p.545) is envisaged. Upper Champagne Member, a widespread deposit thought to extend 60km up the Clarence River, shows an up-section increase in plant material cumulating in thin lenses of coal suggesting more shallow water deposition perhaps in a prodelta muddy shelf environment.

A rhyolitic tuff bed in the upper part of Champagne Member links the unit with Sawtooth Group rocks which have similar tuffs.

2.37 Correlation of Split Rock Formation

Middle Clarence Valley:

Suggate (1958, p.400) gave the name 'Split Rock Formation' to a sequence of Motuan sedimentary rocks overlying Torlesse rocks in the Seymour Stream area, middle Clarence Valley. Reay (1980) divided the formation into three members (*fig. 2.20*). There is a good case for correlation between Split Rock at Seymour Stream and in the Coverham area. From Seymour Stream the unit can be traced down the Clarence River as far as Whiskey Stream, a distance of c.36km, and almost identical rocks can be found along strike in Mead Stream, a further 8km down river. This leaves an unmapped gap of only 8km. *Figure 2.20* correlates between Split Rock in the type section and Coverham areas.

The basal conglomerate of Champagne Member is probably equivalent to Tentpoles Conglomerate (Reay 1980) (*fig. 2.20*) while the majority of Champagne Member is similar to Bluff Dump Member. Ouse and Swale Members may be equivalent to Cold Stream Member.

Split Rock Formation is dominantly alternating sandstone and mudstone but is locally sandstone dominated (Wharfe) and locally mudstone dominated (Ouse, Swale, Cold Stream). The formation is thinner in the Seymour River area cf. Coverham area and this along with a Coverham $\rightarrow$ Seymour, marine $\rightarrow$ non-marine trend suggests that the Seymour area is more proximal than the Coverham area.

In the middle Clarence Valley the Split Rock Formation is overlain by Warder Coal Measures. These are not present at Coverham, however lenses of coal do occur

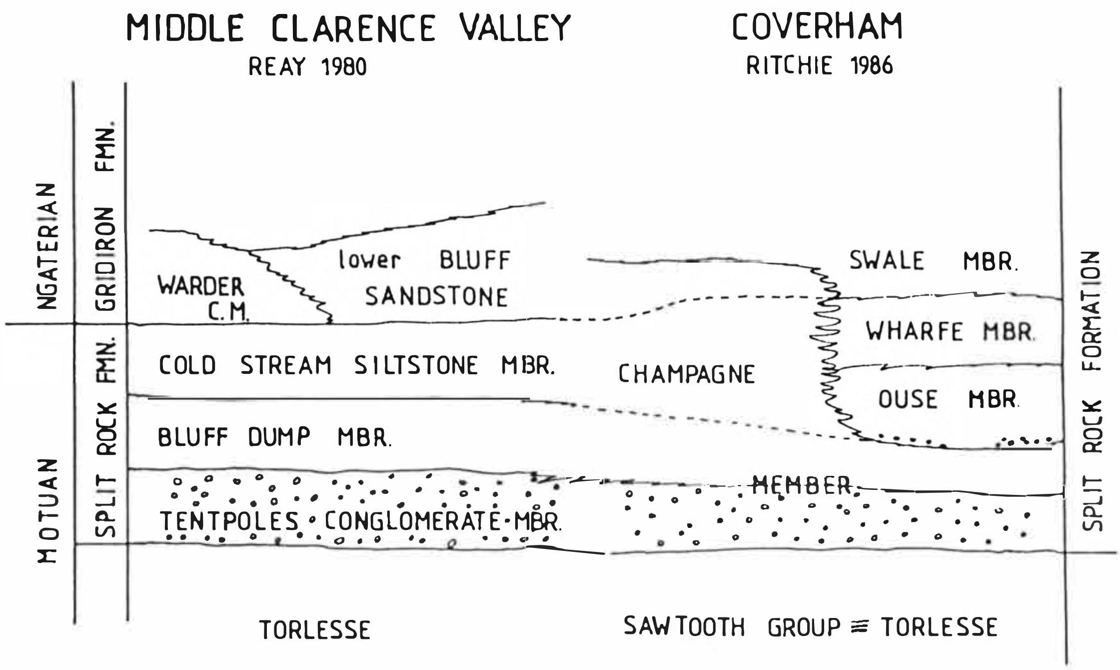


Figure 2.20 Possible Correlation of Split Rock Formation Members at Coverham and Middle Clarence.

in Mead Stream in the upper Champagne Member which is of similar age. Warder Coal Measures are thought to have been deposited in a non-marine environment (Bradshaw and Laird 1980, p.35). By comparison, Warder Coal Measures is a deltaic prograding sandstone lobe whereas Wharfe sandstone is a marine prograding sandstone lobe.

The middle Ngaterian basaltic lava flows comprising Black Rock Volcanics (Reay 1980) are absent in the Coverham area except for perhaps one lens of basalt within Swale Siltstone Member in Swale Stream (G.R. 816175).

At Seymour Stream Reay (1980) considers that the Split Rock Formation formed in a marine fan-delta environment whereas at Coverham submarine slope basin deposition is likely. A shallowing trend from Coverham to Seymour Stream is likely at this time.

Awatere Valley:

Montague (1981) had a reconnaissance look at the Split Rock in the Coverham area during his work near Mt Lookout in the Awatere Valley. Although the two areas have contemporaneous post-Torlesse sedimentary rocks, he could not directly correlate the rocks on a formational level. However, he suggested that the Pikes Formation at Coverham (Champagne Member - this study) had a similar lithology and composition to the Totara Formation immediately overlying the Torlesse in the Awatere. Ouse and Wharfe Member ages are equivalent to Gladstone, Lower Winterton and Upper Winterton Formations in the Awatere. He suggests that any direct correlation would be untenable, the rocks at Coverham being more fine grained and exhibiting continuous deposition from Motuan - Ngaterian whereas in the Awatere, basalt flows occurred in the Ngaterian.

Ngaterian mudstones in the Penk River section (Laird and Lewis 1980) may be correlative with an upper part of the Swale Siltstone Member.

It appears that no good correlation exists between Split Rock Formation at Coverham and the Awatere River, and that the sediments were laid down in quite separate basins at least until the upper part of the Swale Siltstone.

Local Correlation:

Although the Burnt Creek Formation is contemporaneous with the Split Rock Formation, they generally have quite a different character. Flysch in the upper part of Ouse Member does look like Burnt Creek, however it is thought unlikely that any sediment exchange occurred between the two units and that these two areas were some distance apart although in a similar geological setting at the time of deposition (see Chapter IV).

Further Correlation:

It is highly likely that rocks correlative to Split Rock Formation occur in the eastern North Island area where thick Motuan sequences overlying Torlesse-like rocks have been reported e.g. Wairarapa (Moore and Speden 1979, 1984), Johnston (1980).

EAST

2.4 SAWTOOTH GROUP

2.41 Pikes Block

Definition:

Sawtooth Group of Pikes block has been called a wide range of names by previous workers (Table 2.2).

The base of this block is thought to be faulted, probably against other Torlesse-like rocks.

The best reference section is down the ridge from the top of 'The Pikes' (G.R. 834137) to the saddle between 'The Pikes' and 'The Ned' (G.R. 823143), then down Latter's Stream to the base of the Burnt Creek Formation (G.R. 824159).

Distribution:

The rocks are best exposed along the north bank of the Clarence River and in the tributaries of Latter's Stream. They are also exposed in Pikes Stream. The eastern boundary forms a faulted contact with Burnt Creek Formation along the ridge running southwest from 'The Pikes'. To the north and west its contact with the overlying Burnt Creek Formation, which is considerably softer, forms an obvious topographical break-in-slope. Outcrop continues to the southwest across the Clarence River but its extent in this direction is unknown.

On the western slopes of 'The Pikes' massive sandstones form spectacular cliffs surrounded by thick bush (*fig. 2.21*).

Thickness is approximately 3000 metres.

Description:

Pikes block rocks comprise alternating sandstone and siltstone, massive sandstone and massive siltstone. The alternating flysch-like sequences thicken upwards and typically have ss:zst ratios of 1:6. They occur in sequences

EAST		McKay 1886 and 1890	Thomson 1919	Prebble 1976	this study	this study	
Mata	Haumurian	Amuri Limestone	Amuri Limestone	Amuri Limestone	Amuri Limestone		
		Waipara and Lower Greensands	Clarentian (mudstones, sandstones, basalts and conglomerates)	Whangai Shale	Whangai Shale		Coverham Group
	Mp			Paton Sandstone	Paton Sandstone		
Raukumara	Teratan			Burnt Creek Formation	Burnt Creek Formation		
	Rm, Ra			Glencoe Siltstone			
Clarence	Ngat.	Other Secondary and Paleozoic	Pre-Notocene greywackes, argillites	Good Creek Formation	Pikes Block	Glencoe Block	
	Motuan			?	Undifferentiated	Sawtooth Group	
				Greywacke			

Table 2.2 : Stratigraphies developed for the section in Kekerengu River area, EAST portion of study area.

Note : not drawn to relative thickness.

up to 200m thick. Individual sandstone beds are 5cm thick at the base and 15cm near the top. Massive sandstones are up to 20m thick and alternate with massive siltstone which is of similar thickness. Sandstone of the flysch sequence is graded but sandstone of the massive sandstone unit is typically non-graded.

Minor lithologies include conglomerate units up to 20m thick. Beds of white tuff are found throughout the flysch-like lithology.

Below is a list of lithofacies present with relative percentages of each:

$<0.05\%$ L_5 = tuff
c.1.0% L_4 = conglomerate
19% L_3 = massive siltstone
30% L_2 = massive sandstone
50% L_1 = cm-dm bedded flysch-like alternating ss/zst

Conglomerate is granule to coarse pebble grain-size and black coloured when viewed from a distance (G.R. 831139). Sandstones are typically fine-medium grained, well sorted sands: lithic feldsarenite - feldspathic litharenite (Appendix I(a)). 'Cannon-ball' sandstone concretions occur rarely in the flysch sequence. The siltstones are well sorted.

Sandstones are composed of 31% quartz, 17% plagioclase, 7% potassium feldspar, 18% lithic fragments, and small percentages of detrital mica, opaques, laumontite etc. Full descriptions are found in Appendix I(a).

Paleontology and Age:

Recent microfloral collections confirm definite Cretaceous ages for the Pikes block rocks. Low - very low yields of miospores and dinoflagellates are present. Full species lists appear in Appendix II(b) and fossil localities are plotted on Plate 1.

Age is Taitai - Clarence Series but probably Korangan.

Interpretation:

These rocks are thought to have been deposited in a proximal submarine upper fan environment based on abundance of very thick ungraded sandstone, conglomerate and absence of shallow water indicators. Andesitic-rhyolitic volcanism was contemporaneous with deposition.

Saw

Burnt
Creek

fig. 2.21

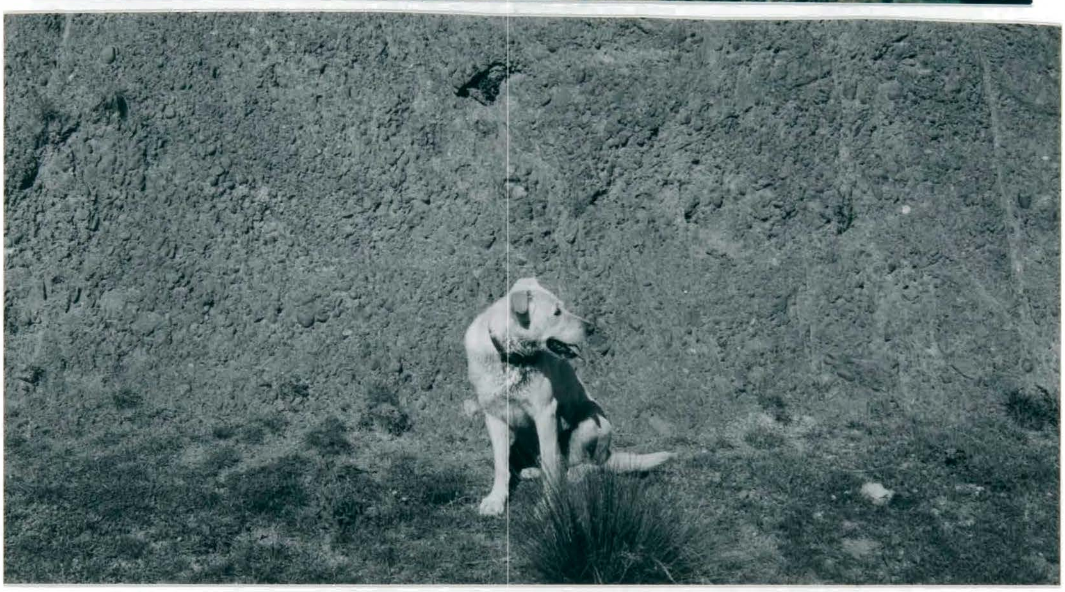


fig. 2.22

fig. 2.23

Figure 2.21 (Top): Sawtooth Group, Pikes Block. Thick sandstones on western slopes of 'The Pikes'. Contact between Sawtooth and Burnt Creek Formation marked. Relief from base of photo to top of 'The Pikes' = c.1000m.

Figure 2.22 (Middle): Ragged Robin Conglomerate (RR) of Sawtooth Group, Glencoe Block - on Kekerengu to Coverham road (G.R. 895153). Well rounded and polished cobble conglomerate. Dog for scale is labrador.

Figure 2.23 (Bottom): Anticline in alternating ss and zst of Sawtooth Group, Glencoe Block on Kekerengu to Coverham road (G.R. 897149). Person for scale.

2.42 Glencoe Block

Definition:

The Sawtooth Group of the Glencoe block was named 'Good Creek Formation' by Prebble (1976) stemming from the use of 'Good Creek Sandstone' by MacPherson (1952) (Table 2.2). These names are abandoned.

The nature of the lower contact and the underlying unit is unknown as neither are exposed in the study area, but the base is thought to be in part faulted.

Prebble (1976) has used the same reference section as MacPherson (1952), that is "... in the bed of the Kekerengu River upstream for half a mile from Good Creek." This section is now poorly exposed. More suitable section is found on the Kekerengu - Coverham road from G.R. 905146 to Beehive Saddle (G.R. 888156) supplemented by along the banks of Kekerengu River between G.R.'s 917151 and 913157.

Distribution:

Glencoe block rocks of Sawtooth Group outcrop over a much larger area north of the Clarence River than the other two Sawtooth blocks. The area is rectangular in shape aligned NE/SW, and is parallel to the other two blocks. Best exposure is along the banks of the Kekerengu River and its tributaries. The Kekerengu - Coverham road provides almost continuous exposure through the width of the whole unit. It is also exposed on the Lady Range, the Sawtooth Range tops, the banks of Boundary Stream and tributaries, and on the banks of the Clarence River. Much of the area is bush covered.

Minimum thickness is approximately 3800m.

Description:

In the Glencoe block, Sawtooth Group comprises thickening upwards flysch-like sequences of alternating sandstone and siltstone° as well as thick massive siltstone and massive sandstone. In some places the sandstone beds of the flysch sequences are 10-15cm thick and the ss:zst ratio is about 1:1. Elsewhere the sandstone beds are 25-30cm thick and the ss:zst ratio is about 4:1. These sequences reach up to 80m in thickness. Sandstones of the flysch sequences are graded but those of the massive sandstones are non-graded. Siltstone is black and unlaminated.

Sole markings occur occasionally on sandstones. Boudinaged sandstone beds, best exposed in Kekerengu River were probably formed by bedding parallel extension during or shortly after deposition.

Other lithologies include thick conglomerate*(up to 244m thick). This is described in detail in section 2.7, p. 72. Massive and well-bedded red and green argillite in beds from 0.5-10's of metres thick are also common and are best exposed in Boundary Stream (G.R. 880145). Tuff beds are found throughout the flysch sequences in beds 10-20cm thick. Their chemistry is discussed in section 2.8, p. 78.

Below is a list of lithofacies present with relative percentages of each:

$<$0.05% L_6 = tuff
c.1% L_5 = red and green argillite
c.2% L_4 = conglomerate
c.15% L_3 = massive siltstone
c.20% L_2 = massive sandstone
c.62% L_1 = cm-m bedded flysch-like alternating ss/zst

Conglomerate has granule-bouldery coarse cobble grain-size. One conglomerate near Ragged Robin (G.R. 893153) is

*see *figure 2.22*
°see *figure 2.23*

described in detail in section 2.7, p.72. Sandstones are typically fine grained, well sorted sands: lithic feldsarenite. Concretions of calcareous sandstone up to 1.5m diameter occur, especially in Benmore Stream. Siltstones are dark grey and unlaminated. Tuffs are pink and reddish, moderately soft and moderately well sorted. Their petrography is described in Appendix I(a). Petrographic analyses of sandstones gives similar results to those of the sandstones of Coverham and Pikes blocks. Full hand-specimen and petrographic descriptions appear in Appendix I(a).

Prebble 1976 (p.18-21) has described Glencoe block rocks in the Kekerengu River in detail.

Paleontology and Age:

Prebble (1976) collected *Inoceramus kapuus - ipuanus* and *Inoceramus* ex-group *warakius - concentricus* from the Kekerengu River. Several samples collected for microflora during this study proved largely barren (see Appendix II).

These fossils suggest that this unit is largely of Urutawan - Motuan age with perhaps the very oldest parts extending down into the Korangan.

Fossil localities appear on Plate 1.

Interpretation:

Glencoe block Sawtooth rocks are thought to have been deposited in a proximal submarine upper fan environment based on thick ungraded sandstones, inversely graded conglomerate and absence of shallow water indicators. MacKinnon (1980, p. 75) came to a similar conclusion after studying a small part of the unit in Kekerengu River.

This interpretation stands for Coverham and Pikes blocks as well because all three are thought to be genetically related although now outcropping as three distinct packets of rock separated by large faults (see Chapters III, IV).

Source rocks of the Sawtooth Group were probably part of a continental area or mature plutonic-magmatic arc. Evidence is in their high quartz content, contemporaneous rhyolitic volcanism, and the acid igneous clasts in the conglomerates. Many workers have suggested this area lay to the east (Coombs et. al. 1976, Andrews et. al. 1976, Bradshaw et. al. 1981).

2.43 Correlation of Sawtooth Group

Sawtooth Group rocks have not been identified outside the Coverham area. This is due to the lack of detailed work in the Torlesse in the Marlborough area and to the sparsity of datable fossils in these rocks. Prebble (1976) reported Motuan ages for fossils in Torlesse rocks in the Waima River catchment to the north. This area has not been mapped in detail but recent work in the area suggests that the Clarence Fault may wrap around here thrusting the Torlesse over younger rocks (G. Browne - pers. comm .). It is possible that this Motuan Torlesse and the Sawtooth are correlative. Elsewhere, similar Urutawan - Motuan ages have been reported in the Awatere, e.g. Penk River (Laird and Lewis 1980).

Very similar rocks complete with sections showing a low degree of deformation and consequently displaying sole marks, convolutions, ripple marks, well graded beds etc. can be found within the rocks of the Seaward Kaikoura Range (near Blind Saddle c.60km southwest of the study area - writer's observation).

Further correlation speculation is unwarranted in this largely unknown body of rock. Detailed mapping studies will eventually outline the extent of the Sawtooth Group and correlation can then be made.

2.5 COVERHAM GROUP

Although Burnt Creek Formation was assigned to the Iwitahi Group by Lensen in Suggate et. al. 1978 (p.384), it is retained in the Coverham Group for the purposes of this thesis because of new mapping and interpretation. Reassessment of the make-up of various Groups of formations will be undertaken at a later date.

2.51 Burnt Creek Formation (Bc)

Definition:

Hall (1965) introduced this name for the rocks directly overlying the Torlesse-like rocks in Burnt Creek. Usage has been extended into the Kekerengu River catchment by Prebble (1976).

The basal contact with Undifferentiated Sawtooth Group is for the large part an angular unconformity, but in a few places it is faulted (Plate 1). It forms an obvious topographic break especially easily seen north of 'The Pikes'.

Although not published, Hall describes a type section from Burnt Creek (Hall 1965, p.28). This is retained. A detailed measured stratigraphic section along Latter's Stream is displayed in *figure 2.24*.

Distribution:

The known extent of this formation has been extended by further mapping in this study.

Burnt Creek Formation outcrops on the western and northern boundaries of the Coverham and Pikes blocks of the Sawtooth Group (Plate 1). Best developed in Burnt Creek, it outcrops on the southern banks of

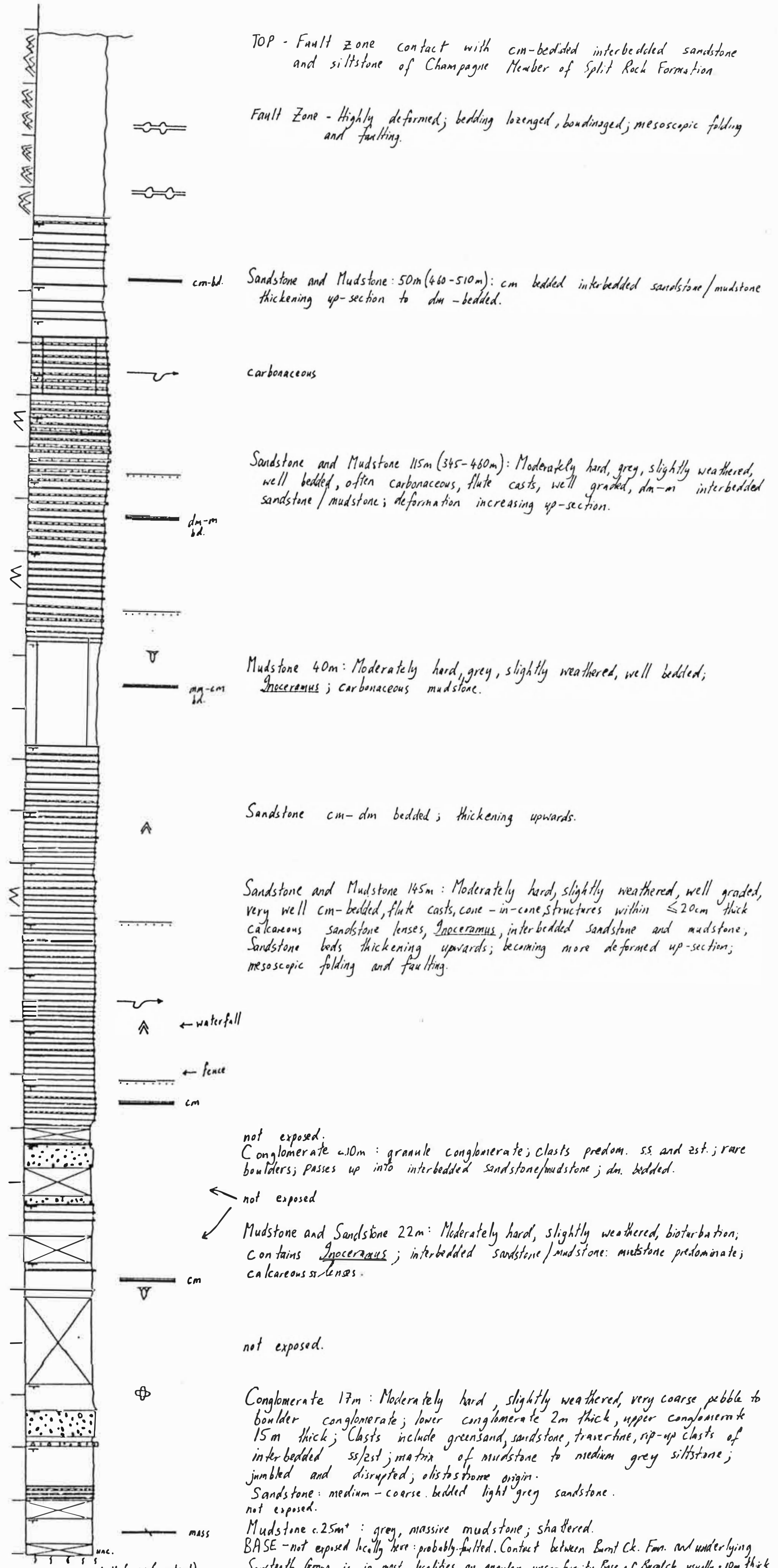


Figure 2.24: Measured stratigraphic section of Burnt Creek Formation; Latter's Stream.
GR. 825159 (base) to GR. 820163 (top) - see also C.C.P. Measured section Detail Sheet (Appendix III)
[see graphic symbols key, page 172]

Wharfe Stream, is well exposed in Latter's Stream, and continues to strike in a southwesterly direction down Ouse Stream, straddling the Clarence River and retaining its thickness almost to Gibson Stream. Further outcrop is found in the lower reaches of Mead Stream but the exact relationship between this outcrop and the remainder of the formation is unclear due to problems crossing to the south bank of the Clarence River. Faulting is certainly involved but the structure in this region is highly confused and complex (Plate 1). Burnt Creek rocks outcrop very near the summit of 'The Pikes' and continue in a gradually thinning strip just east of the Pikes Fault to the southwest forming the west limb of an anticline. It is not known whether the rocks outcrop south of the Clarence River here. Northeast of 'The Pikes' the unit thickens near Burnt Saddle but then thins once again to the east. Good exposure is found in the upper reaches of Kekerengu River but in Benmore Stream, active slumping has masked the contact and disrupted the beds. Further to the southeast it is faulted out apart from a 20m thick lens in Glencoe Stream. Hall (1965) reports about 400 metres thickness in Burnt Creek. At the mouth of Ouse Stream the formation is 660 metres thick while in the Kekerengu River catchment it thins to approximately 150 metres.

Description:

Burnt Creek Formation primarily comprises flysch-like alternating sandstone and mudstone and massive mudstone. In some places e.g. Wharfe Stream (G.R. 842172) and the mouth of Ouse Stream (G.R. 802132), sandstone is subordinate to mudstone with ss:ms ratio of 1:10. However, elsewhere e.g. Latter's

Stream (G.R. 823161), the sandstones are cm-bedded with ss:ms ratios of 1:2 (*figs. 2.25, 2.27*). These sandstones gradually thicken upsection to alternating dm-bedded sequences with ss:ms ratio of 2:1. The thin bedded alternating sequences are up to 100m thick while the thicker bedded alternating units are up to 120m thick. Mudstone units are up to 40m thick.

Sandstones of the alternating sequences are well graded sometimes with granular bases and well bedded. Bouma ABE with thickened A horizons are common in the thicker sandstones. The thin sandstones more often only show Bouma AE with B occasionally developed. Mudstone is dark grey and becomes more predominant to the east. Pebbly mudstones are common.

The widespread basal unit is a very coarse pebble conglomerate (*fig. 2.26*) which is 10-15m thick and appears to fill in hollows in the uneven surface of the Sawtooth Group rocks.

A full description and compositional analysis is presented in section 2.7 (p.73). Finer granule conglomerate occurs in thin ($<$10m) beds in the lower 150m of the formation.

Below is a list of lithofacies present in this formation.

L_5 = cm-dm bedded flysch-like alternating sandstone/ mudstone

L_4 = paraconglomerate (olistostrome)

L_3 = well bedded mudstone

L_2 = massive mudstone

L_1 = conglomerate

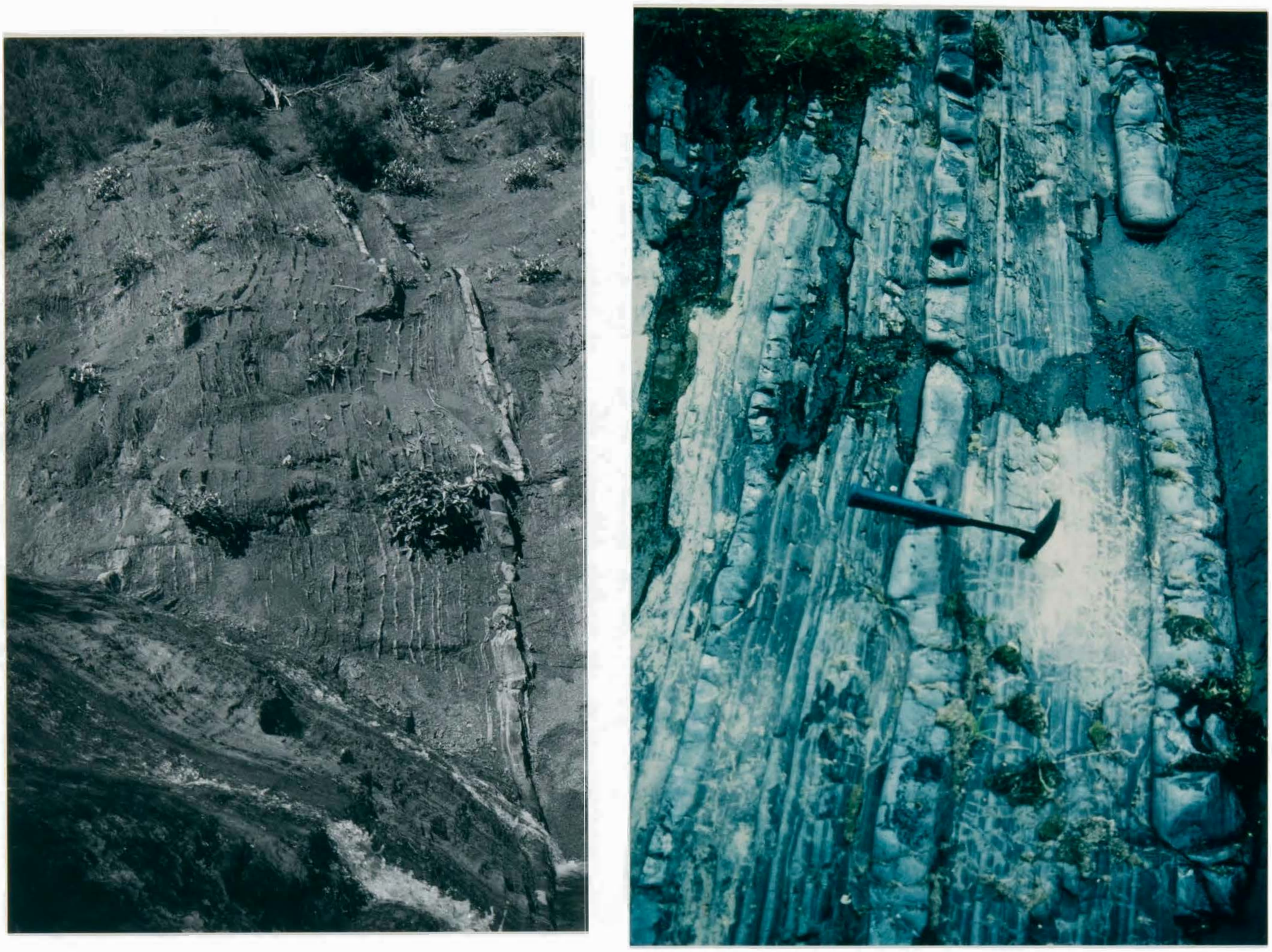


Figure 2.25 Cm-bedded alternating sandstone and mudstone of Burnt Creek Formation, Latter's Stream (G.R. 823161). Facing to right. Hammer for scale is 33cm long.

Figure 2.26 Basal coarse pebble conglomerate of Burnt Creek Formation, Pikes Stream, boulder in stream-bed (G.R. 842168). Igneous clasts (i), sandstone (s), jasperite (j). Lens-cap is 5cm in diameter.

Figure 2.27 Alternating sandstone and siltstone of Burnt Creek Formation, on Kekerengu - Coverham road (G.R. 858166). Dog for scale is labrador.

Thicknesses and stratigraphic position of these various lithologies appear in *fig. 2.24*.

Syn-sedimentary structures are widespread and include olistostromes, slumps, flute casts, boudinage, rodding, bioturbation and discrete trace fossils. A 17m thick endolistostrome (after Elter and Raggi (1965a) and Abbate et. al. (1970)), occurs in Latter's Stream (G.R. 825160). This chaotic paraconglomerate contains clasts of greensand, sandstone, travertine, and 'bed-chunks' of sandstone and mudstone in a mudstone matrix. It is further described in *fig. 2.24*. A well displayed slump with parallel bedding above and below occurs at G.R. 858166. Large worm traces (10 x 3cm) are well developed near Chaytors Saddle (G.R. 867165). Diagenetic cone-in-cone structures in calcareous sandstone are well developed in Wharfe Stream (G.R. 847174). Boudinage on a small scale producing rodding is displayed rarely in Wharfe Stream (G.R. 844173). The sandstone beds are often lensoid and pinch and swell in many places. This is thought to be a combination of sedimentary processes and tectonic bedding parallel extension which only rarely proceeded to the extent of producing boudinage structures.

Sandstones are typically medium grained, well sorted sands: feldspathic litharenite (*fig. 2.2*, p.17). They are also often carbonaceous, calcite cemented, fossiliferous and glanconitic. Generally the grainsize as a whole decreases to the east. Full sandstone hand-specimen and petrographic descriptions are found in Appendix I(a).

Figure 2.24 provides additional detailed descriptions of the formation in the Latter's Stream measured section.

Both Hall (1965) and Prebble (1976) have described this formation.

Paleontology and Age:

Hall (1965) dated this formation at his type section in Burnt Creek as Mangoatanean - Teratan on the basis of occurrence of *Inoceramus*. Prebble (1976) assigned a Teratan age for the formation in the Kekerengu River catchment on the basis of *Inoceramus opetius* and *Inoceramus nukeus*.

Recent microfloral and macrofaunal dating (J.I. Raine and I.G. Speden - pers. comm.) has given Clarence Series ages for the Burnt Creek Formation in Latter's and Ouse Streams. The beds at the mouth of Ouse Stream yield a Motuan - Ngaterian age (probably Motuan) while in Latter's Stream we have a late Motuan - Ngaterian age. Teratan fossils have also been collected in Latter's Stream. Full fossil lists and dates are listed in Appendix II and fossil locations appear on Plate 1.

Burnt Creek Formation youngs to the east from a Motuan - Teratan date on the Pikes block to Teratan only on the Glencoe block.

Interpretation and Correlation:

The thick basal conglomerate of the Burnt Creek Formation is, like the basal Champagne Member conglomerate, thought to have been deposited by mass-flow processes and to have its source in other Sawtooth or Sawtooth-like rocks. The conglomerate overlies previously deformed Sawtooth and is in turn overlain by mudstones overlain by a coarsening upward sequence of turbidite-like flysch. These rocks are interpreted as slope basin deposits which accumulated in a restricted basin in the same way as the Split Rock Formation (p.43). Measurement of flute casts in Latter's Stream indicate current direction was from what is now the south southeast direction (*fig. 2.28*).

Although the lower Burnt Creek rocks are contemporaneous with and in close proximity to the Split Rock Formation (Champagne, Wharfe, Ouse, Swale Members) and Nidd Formation, they are clearly different - a conclusion reached by all previous investigators e.g. Hall (1963), Gair (1967). This suggests they were deposited some distance away in a different sedimentary cycle. Given the extent of the Split Rock Formation, Warder Coal Measures to the southwest and the great thickness of Ngaterian volcanics to the west in the Awatere Valley and the absence of Burnt Creek equivalent (Montague 1981), the zone of Burnt Creek sedimentation most likely lay to the east of Split Rock sedimentation. However movement on the Awatere and Clarence Faults may have displaced further Burnt Creek rocks, and this must be taken into account. Sedimentation was much slower in the Burnt Creek Formation than in the contemporaneous Split Rock Formation.

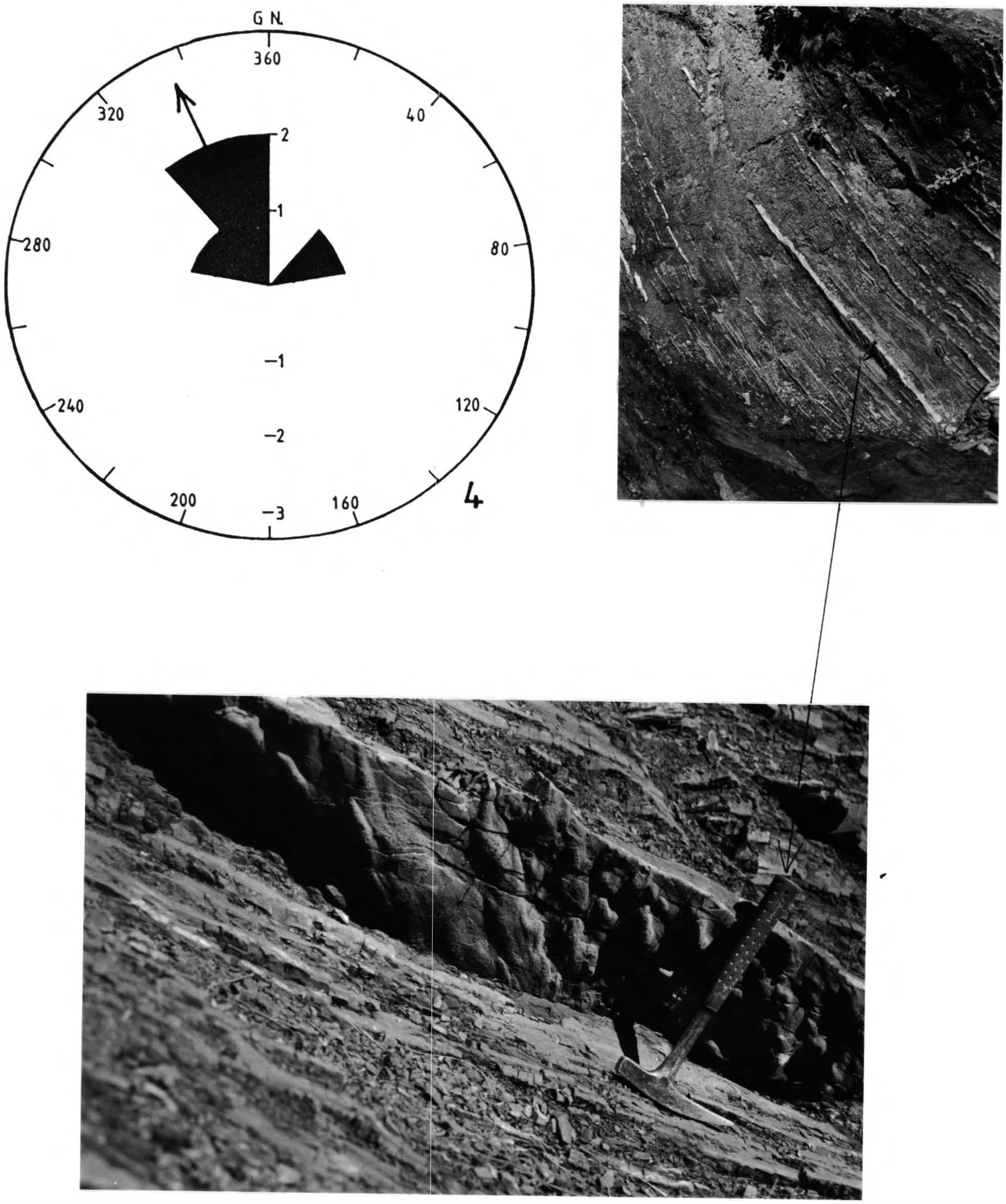


Figure 2.28 Top Left: Rose diagram of current direction indication data (flute casts) in Burnt Creek Formation (4 readings), Latter's Stream. Arrow indicates dominant direction of current flow. Increments equal 1 reading. Segments = 40°. Bottom and Top Right: Flute casts in cm-bedded flysch lithology, Burnt Creek Formation, Latter's Stream. Hammer for scale is 33cm long.

2.6 IGNEOUS ROCKS

Basaltic dikes and sills associated with the Tapaenuku Volcanic Complex nearby, outcrop only rarely throughout the map area and although mapped on Plate 1 have not been studied in detail. In Ouse Stream (G.R. 815158) a sill appears to have been emplaced penecontemporaneously with sedimentation. In Swale Stream (G.R. 816175) a vesicular basaltic dike intrudes and is intermixed with Swale Siltstone. A biotite lamphrophyre-like dike intrudes basal conglomerate of Champagne Member in Mead Stream (G.R. 770135). Emplacement of this dike predates tilting of the Champagne Member and therefore is likely to be penecontemporaneous with deposition i.e. intra-Motuan. Overall, it seems that these sills and dikes were emplaced penecontemporaneously with the sediments, while the sediments were still unindurated. They have undergone the same deformation as the sandstone-mudstone sequence. Petrographic descriptions of volcanic dike rocks appear in Appendix I(a). Detailed description and field mapping of the Tapaenuku Volcanic Complex has been undertaken by Nicol (1977).

2.7 ANALYSES OF CONGLOMERATES

Introduction:

Special treatment is given here to the various conglomerates in the study area, firstly because they are useful as marker horizons helping to unravel the structure in the Sawtooth Group rocks especially, and secondly, because clast compositions provide an indication of the provenance of these rocks or at least an idea of the range of sources present at the time of deposition.

Each conglomerate analysed has been highlighted, named, and coded on the geological map (Plate 1) and described below. The sample sites have been marked with a black square on Plate 1.

The counting method used was to mark out a 500 x 500mm square on the conglomerate then to count all the clasts within that square.

Table 2.3 lists the composition of the clasts in percentages. Although there is no doubt that composition changes from place to place in the conglomerate, this analysis gives a general compositional picture. A selection of the more interesting looking clasts were thin-sectioned (see bottom of Table 2.3) and this helped to refine compositions. Detailed descriptions of thin-sectioned clasts can be found in Appendix I(a).

Note that conglomerates M and BB are both the Champagne Member basal conglomerate.

	Sawtooth RR		Champagne Member M		Champagne Member BB		Ouse Member O		Burnt Creek Formation BC	
	# clasts	%	# clasts	%	# clasts	%	# clasts	%	# clasts	%
Siliceous Rocks										
quartz (clear and green)	178	41.6		3		11		0.2	10	9.7
jasperite	34	7.9		0.2		0.5		0.1	3	2.9
	212	49.5		3.2		11.5		0.3	13	12.6
Igneous Rocks										
acid igneous	18	4.2		7		23		0.1	10	9.7
mafic igneous										
	18	4.2		7		23		0.1	10	9.7
Sedimentary Rocks										
quartzite	80	18.7								
sandstone	102	23.8		55.8		16		99.2	66	64.1
black argillite	11	2.6		3		15			10	9.7
light brown mudstone									4	3.9
tuffaceous sandstone				31		30				
mud-chip breccia						2				
	193	45.1		89.8		63		99.2	80	77.7
others	5	1.2				2.5		0.4		
	5	1.2				2.5		0.4		
	428	100		100		100		100	103	100
Compositions from thin-section analysis	rhyodacite dacite rhyolitic ignimbrite (3) adamellite sandstone		dacite limestone adamellite (2) rhyodacite siltstone		granite dacite tuff rhyodacite (2)		sandstone mudstone		granitic graniodiorite tuff dacitic ignimbrite	

Table 2.3 Conglomerate clast count analyses and thin-section compositions of interesting looking clasts

Descriptions:

RR - Ragged Robin Conglomerate; Sawtooth Group; Glencoe Block; Ragged Robin trig (G.R. 893153).

Overall, this conglomerate is inverse-normal graded (Walker 1983), matrix supported, well rounded, granule to bouldery coarse cobble conglomerate (*fig. 2.22*). The conglomerate is bimodal with polished cobble clasts and boulders of sandstone with a maximum clast diameter of c.50cm. The matrix is brown, moderately soft, moderately well sorted, medium-coarse sandstone. There is no obvious imbrication. At its base the conglomerate initiates with the underlying flysch sequence becoming pebbly, then up into the conglomerate proper, then pebbly sandstone and back into flysch. Maximum thickness = 244m on 'Ragged Robin'. To the south the conglomerate thins rapidly and pinches out in the lower reaches of Boundary Stream.

M - Mead Stream Conglomerate; Champagne Member (base) of Split Rock Formation; Mead Stream (G.R. 770134).

Matrix supported, well rounded, bimodal, coarse pebble conglomerate with dm-m thick sandstones interbedded within it. Well polished pebbles and boulder size clasts of sandstone make up the bimodal clast population. The matrix is brown, medium-coarse sandstone. Maximum thickness is 25m+. Two beds of conglomerate occur separated by c.20m of flysch, representing the basal unit of the Champagne Member on the westerm limb of the Ouse Anticline and can be traced around the anticline to conglomerate BB in Ouse Stream which is on the eastern limb.

BB - Big Bend Conglomerate; Champagne Member (base), Ouse Stream (G.R. 802146).

Generally clast supported, well rounded, bouldery, very coarse pebble conglomerate (*fig. 2.5*). Matrix is brown sandstone. Maximum thickness is 25m+. The base of the conglomerate is not seen in this locality due to faulting and the consequent steeply plunging nature of the anticline here (Plate 1). Elsewhere, the base is often disrupted by faulting causing shear losenge development. Large, light coloured, highly angular, tuffaceous sandstone boulders (*fig. 2.5*) similar to tuffaceous sediments outcropping nearby, suggest local derivation.

O - Ouse Conglomerate; Ouse Member (base), Ouse Stream (G.R. 817164).

Clast supported, light grey, moderately soft, well rounded-angular, coarse pebble conglomerate (*fig. 2.10*). Matrix is sandstone. Contains rare boulders and rip-up clasts of sandstone, sandstone clasts with carbonaceous layering and *Inoceramus* fragments. The ratio of sandstone to siltstone clasts is 60:40 and these lithologies make up over 99% of the clasts. Thickness is 2-3 metres with scattered pebbles extending into the overlying siltstone. This conglomerate is only local and lensoid at the base of the Ouse Member.

BC - Burnt Creek Conglomerate; Burnt Creek Formation (base), Pikes Stream (G.R. 843169).

Fining upwards, matrix supported, well rounded and polished, granular, cobbly, very coarse pebble conglomerate with 15cm± sandstone lenses within (*fig. 2.26*). Matrix is a brown medium grained sandstone. The upper part of the conglomerate is predominately sandy with lenses of conglomerate. Thickness is 10-20 metres. It is lensoid at the base of the Burnt Creek Formation, filling in hollows in the top of the Sawtooth Group.

Quartz and sandstone clasts:

One obvious result of the clast counting analysis is the high quartz clast content of the Ragged Robin (Sawtooth) conglomerate cf. Coverham Group conglomerate (Table 2.3). Another feature is that the Coverham Group conglomerates contain higher proportions of sedimentary rock clasts than the Sawtooth conglomerate. These compositions suggest that the Sawtooth conglomerates are more mature than those of the Coverham Group.

All the conglomerates are bimodal with well rounded and highly polished pebble size clasts and boulders of sandstone. The highly polished nature of the pebbles suggests that they have been recycled from older conglomerates. The sub-angular sandstone boulders are not likely to have travelled far and represent local erosion products. Highly angular tuff clasts found in the basal Champagne Member conglomerate (*fig. 2.5*, p.23) can be traced to an adequate source in the Sawtooth close-by. This is an indication of active local, probably tectonic induced erosion (see Chapter III). The Ouse conglomerate is completely locally derived, probably from nearby underlying Champagne and Sawtooth rocks.

Perhaps rather than the Sawtooth conglomerates being more mature (first paragraph), the difference in composition is due to the Coverham Group conglomerates having a higher percentage of local derivation due to tectonic induced erosion (see Chapter III).

Acid igneous clasts:

Another feature of the clast analysis is that acid igneous clasts make up a significant proportion of all the conglomerates (Table 2.3) except for the Ouse Member conglomerate.

Acid igneous clasts have been reported elsewhere in Cretaceous Torlesse conglomerates. Johnstone and Brown (1973) describe dacite, rhyolite, granophyre and ignimbrite clasts in Upper Jurassic - Cretaceous conglomerates in the eastern Wairarapa (see also Moore and Speden 1984, p.57). Smale (1978) reports rhyolitic, andesitic and granitic clasts in lower Cretaceous Torlesse conglomerate at Ethelton, North Canterbury. Andrews reports porphyritic acid volcanics as the dominant clast type in early Cretaceous Pahau rocks from the Pahau River area in North Canterbury (Bradshaw and Andrews 1980). It is clear that acid igneous clasts and acid tuffs are widespread in the Cretaceous part of the Torlesse Supergroup.

Although they are likely to be recycled in the study area as well as at Pahau River, the acid igneous clasts must have had an ultimate source probably of ?Triassic - Cretaceous age (however as the clasts are undated their true age can only be guessed).

It should be noted that there can be a close, possibly magmatic, relationship between rhyolite and granite. Rhyolite may extrude from the top or base of granite plutons (Roddick 1983). Therefore granitic and rhyolitic clasts may have a common source.

Possible Triassic - Cretaceous granitic source rocks include: 1. Western Province: Rahu Suite granitoid rocks (Jurassic - Cretaceous) (Karamea Batholith) of the Buller Gorge, for example, Berlins Porphory which gives ages of between 105-109 Ma and produced rhyolitic tuffs (Adams and Nathan 1979). Separation Point Batholith, Rotoroa Igneous Complex (Permian - Cretaceous) or Riwaka Igneous Complex (Devonian - Cretaceous) rocks (Tulloch 1983) are also possible sources; 2. Mt Somers Volcanics which produced a high potassium calc-alkaline, andesitic-dacitic rhyolitic suite and is most recently dated at 89±2 Ma (Barley 1986); 3. Marie Byrd Land granitic rocks (Carboniferous - Cretaceous) which are thought to be a likely source for the Torlesse Supergroup detritus (Bradshaw et. al. 1983); 4. Banks Peninsula rhyolite (mid-Cretaceous); 5. From the same source as the acid tuffs present throughout the rocks of the study area (see section 2.8). The thickness of the tuffs ($\leqslant$2m) suggests that this was nearby but as yet a local source has not been found. The volcanics would have been active in the Urutawan and perhaps before that but no more recently than the Motuan (see section 2.8).

Mt Somers and Banks Peninsula rhyolites are too young. If one restores the displacement on the Alpine Fault the Buller Gorge acid plutonics are on the wrong side of the median tectonic boundary and 500km away. The Haast Schist was exposed and being uplifted in the Cretaceous (Adams et. al. in press) therefore one would expect schist debris in these conglomerates as well. None is evident. Marie Byrd Land has Carboniferous - Cretaceous granites and acid volcanics (Le Mesurier and Wade 1976) and would appear to be a likely original source for the acid igneous clasts. This igneous activity may have represented uplift and cooling of the granite batholiths during the final uplift phase of the Rangitata Orogeny in the S.W. Pacific area (Adams and Oliver 1979). The acid igneous clasts within conglomerates would have been emplaced into the accretionary prism and then eroded from the Rakaia Terrane and deposited in the Pahau Terrane where they may have again been recycled into sequences further down the Pahau sediment's slope. An additional ultimate source from the acid volcanism which produced the andesitic-rhyolitic tuffs throughout the study area is possible.

Source of Conglomerate:

It is likely that the source of the acid igneous clasts is a valuable clue to source of the conglomerate as a whole. A conglomerate source in the Western Province seems unlikely (see above). Erosion of the Rakaia and Pahau Terrane conglomerates and transport to the Coverham sequences by downslope mass movement and longshore currents, supplemented with erosion products from local tectonic activity and input of clasts from local acid volcanic activity seems more likely. Thick conglomerates with similar compositions found in the Pahau River area (op. cit.) could be a possible source. Erosion of 'older' Pahau and Rakaia Terranes has been suggested as a sediment source for the 'younger' Pahau by Bradshaw et. al. 1981 and MacKinnon 1983 (this is discussed further in Chapter IV).

2.8 GEOCHEMISTRY OF TUFFS

Field Relationships and petrography of tuffs:

White to reddish andesitic-rhyolitic tuff beds appear sporadically throughout all three blocks of Sawtooth Group (Torlesse) rocks in the study area and have also been found in one locality in the Champagne Member of Coverham Group. Tuff bed thickness varies from 15-200cm+ and the constant thickness in individual beds suggests they were incorporated into these submarine sedimentary sequences by means of air-fall pyroclastic volcanic activity with little reworking. They can often be traced for up to 1km along strike although most have been disrupted by subsequent faulting. The tuffs are thinnest in the Glencoe Block (10-15cm) and thickest in the Pikes and Coverham Blocks (50-200cm). This may indicate that Glencoe Block was further from the source than Pikes or Coverham Blocks or otherwise further from the dispersal axis.

Positions of tuff-beds encountered during the study have been marked (T) on the geological map (Plate 1) and form-line map (Plate 2).

Hand-specimen and petrographical description of the 11 tuff samples collected appear in Appendix I(a). In hand-specimen they are typically: white to reddish, soft, moderately well sorted, moderately altered, medium grained and veined with calcite and laumontite. In thin-section they display orthoclase and quartz phenocrysts in a fine grained groundmass with a tuffaceous texture. Their mineralogy indicates a rhyolitic composition.

Geochemical Analysis:

Nine tuff samples were analysed for major and minor elements and selected data appear in Table 2.4. A full set of geochemical data is presented in Appendix IV.

A conclusion from the major element data is that these are highly carbonated samples in which alkalis (Na and K) have been replaced by Ca. However, the silica concentrations suggest that they represent a series from andesite-rhyolite (i.e. SiO_2 recalculated by $\frac{100}{\text{total-L.O.I.}}$).

For altered igneous rocks trace element data are more reliable than major for the deduction of tectonic settings. If we assume the rhyolitic tuffs will not be significantly different in chemistry from petrographically equivalent granites, we can plot some of the trace elements on the discrimination diagrams of Pearce et. al. 1984 in his study of granites. *Figure 2.29* is a log-log plot of Nb vrs Yppm. From the data it is clear that the tuffs in the study area are either VAG (volcanic arc granites/rhyolites) or syn-COLG (syn-collision granites/rhyolites). The geological setting implies that these are most likely to be subduction-related rhyolites.

Comparison with Mt Somers Rhyolites:

The Mt Somers Volcanics (intermediate - acid suite) of mid-Canterbury, erupted onto an eroded surface of Torlesse sediments within a similar subduction-related setting to the Sawtooth rocks (see Oliver et. al. 1979, Barley 1986). If

Saw	14	58	121	121A	121B	178	179	185	198
SiO_2	67.701	62.411	54.886	58.532	47.362	60.873	71.541	63.167	68.455
TiO_2	0.362	0.432	0.321	0.408	0.307	0.505	0.220	0.137	0.266
Al_2O_3	15.900	15.821	20.478	18.194	16.950	17.589	13.578	17.536	13.106
Fe_2O_3	2.019	3.633	1.695	2.344	2.017	3.138	0.728	0.948	2.281
MnO	0.028	0.062	0.020	0.038	0.224	0.058	0.018	0.034	0.055
MgO	0.530	0.881	0.483	0.780	0.559	0.848	0.244	0.101	0.526
CaO	4.152	7.240	10.551	9.260	16.463	7.011	5.777	8.714	6.663
Na_2O	2.626	0.461	0.484	0.485	0.470	1.553	0.997	0.028	0.622
K_2O	2.014	0.694	0.636	0.333	0.551	0.751	0.548	0.415	0.339
P_2O_5	0.066	0.129	0.095	0.183	0.087	0.120	0.070	0.039	0.075
Loss	4.560	7.770	10.930	9.770	15.350	7.280	6.690	9.200	7.160
Total	99.959	99.535	100.579	100.327	100.340	99.725	100.411	100.319	99.548
SiO_2*	70.966	68.012	61.223	64.636	55.727	65.848	76.334	69.324	74.095
Cr(ppm)	12	23	14	13	18	26	9	3	13
Ni	7	10	6	8	10	7	2	1	2
V	24	50	35	45	36	45	18	16	13
Rb	67	23	21	12	19	34	24	6	13
Sr	613	715	554	434	488	474	499	398	338
Ba	89	297	739	41	118	150	186	207	53
Nb	17	9	11	5	12	12	14	4	14
Y	24	23	31	14	31	46	27	22	21
Zr	233	166	228	172	188	334	120	216	179

Table 2.4 Major and trace element analyses for Sawtooth Group tuffs. Tuff names: Saw 179, 198 rhyolite; Saw 58 dacite; Saw 14, 121A, 185 andesite/dacite; Saw 121B, 121, 178 andesite; *SiO_2 recalculated volatile free

rhyolite analyses from Barley 1986 (Table 5) are plotted on *figure 2.29* and *2.30*, there is some overlap with the Sawtooth samples. This supports the contention that volcanics from both groups were erupted in similar tectonic environments.

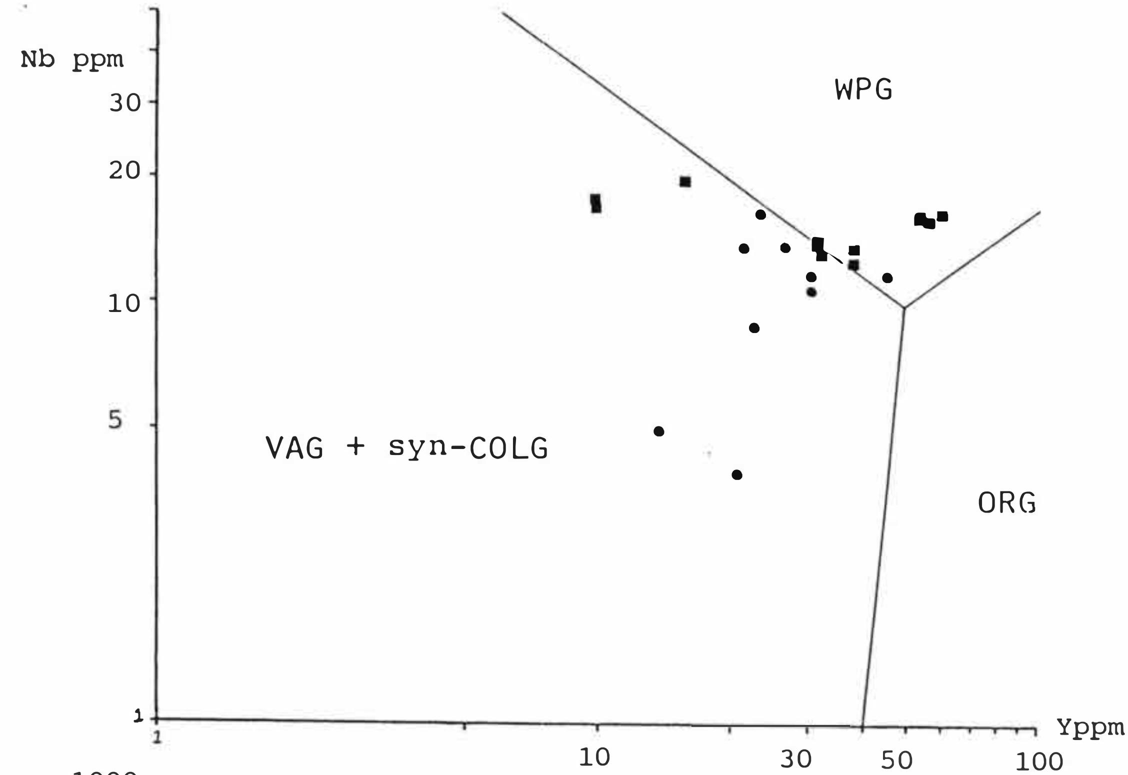
Mt Somers Volcanics are dated at 89±2 Ma (Barley 1986) while the Sawtooth Group tuffs lie within rocks dated at Urutawan - Motuan (107-98 Ma). That is an age difference between the two of c.10-15 Ma. This may indicate that there was oblique subduction of a ridge with migration of a volcanic belt from north to south, or if one takes account of rotation, northeast to southwest.

Other Cretaceous Acid Tuffs:

Rhyolitic tuffs dated at 105-109 Ma which occur in the Buller Gorge area in the Berlins porphory of the Rahu granitoid rocks (Karamea Batholith) (Adams and Nathan 1979), would probably have been too remote (400-500km) to provide such thick rhyolitic tuffs.

Moore and Speden (1984, p.65) report acidic tuffs in coeval, probably also subduction-related, rocks of the eastern Wairarapa, North Island, and Moore (1978) also reports their presence on the Raukumara Peninsula. I have seen them in the Seaward Kaikoura Range c.50km south of the study area near Mt Saunders where they are up to 1m thick and quite common (Miles Reay - pers. comm). It is clear that they are widespread in late Early Cretaceous rocks.

It has been suggested that mid-Cretaceous volcanic rocks may underlie much of the Canterbury Plains (Barley 1986).



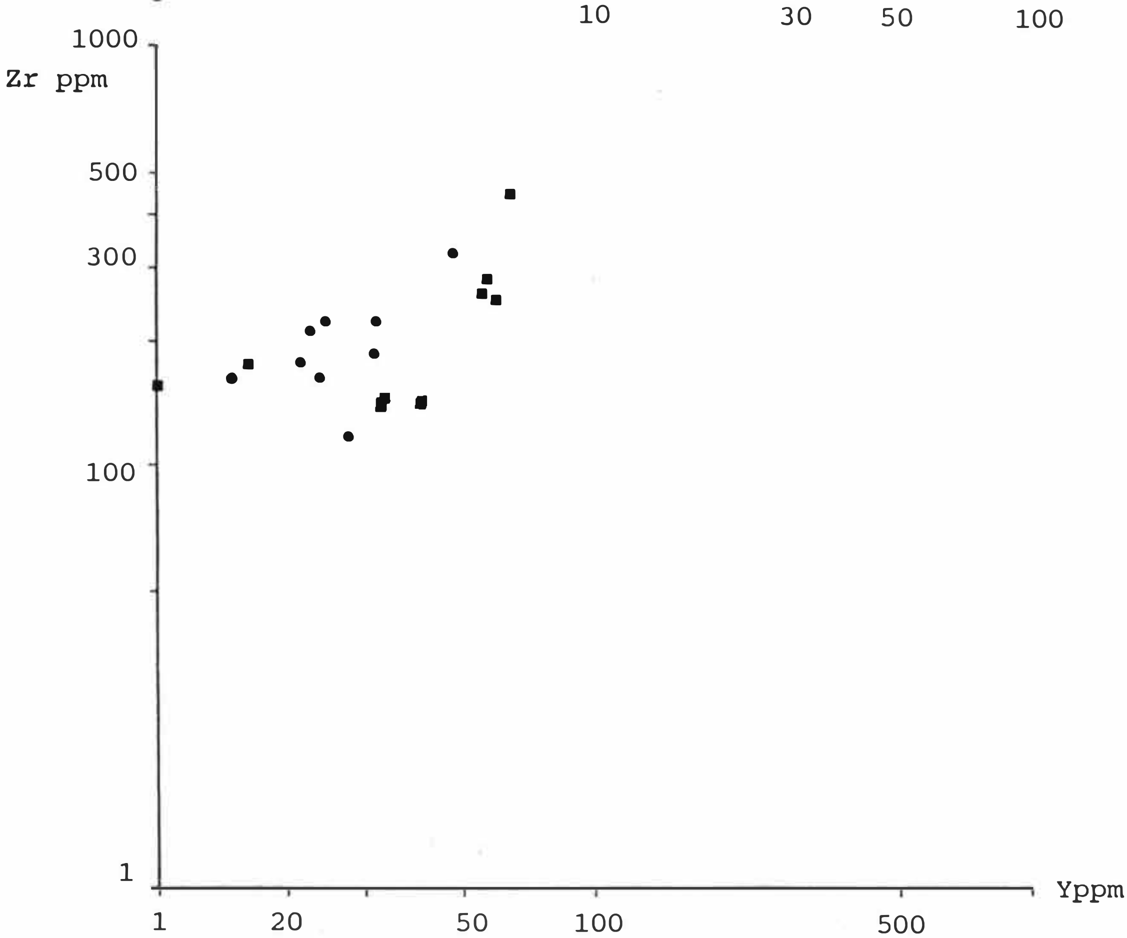


Figure 2.29 (Top): Nb-Y log-log discriminant diagram for syn-collision granites (syn-COLG), volcanic arc granites (VAG), within plate granites (WPG) and ocean ridge granites (ORG). Circles are data from this study; squares are data from Barley 1986, fig.5 -- Data from Mt Somers rhyolites.

Figure 2.30 (Bottom): Comparison of log-log Zr-Y plots for tuff data of study area (circles) and Mt Somers area - Barley 1986 (squares).

CHAPTER III

STRUCTURE

INTRODUCTION

Description of the structure of the Clarence River-Coverham area is difficult due to the unusual nature of the structures themselves and the great variation in intensity of development from place to place. In general, structural complexity is greatest near the major faults. Intensity of deformation has influenced concepts of stratigraphy and geological history in the past, for example Stevens and Speden (1978, p.282) remark that the change from Sawtooth to Coverham Group rocks is from "... indurated, structurally complex, steeping dipping, sparsely fossiliferous Torlesse-like sequences to less indurated, structurally simpler, open-folded, concretionary fossiliferous sequences." The inclusion of deformation as a criterion is misleading and has resulted in areas of Split Rock and Burnt Creek Formations being mapped as Sawtooth Group. Near major faults young formations grade into zones of strong deformation which masks their true identity.

The structural geology differs strongly across the Ouse Fault (Plates 1, 2), and because structural relationships to the EAST are more straightforward they will be described first.

3.1 GLENCOE AND PIKES BLOCKS

The Glencoe and Pikes blocks are separated by the Pikes Fault. Within both blocks the major structure is quite simple, comprising large, generally straight limbed folds in Sawtooth Group overlain with obvious angular unconformity by Burnt Creek Formation (Plates 1, 2). The Burnt Creek Formation and overlying units are folded into northeast plunging anti-clines with part of a complementary syncline in the West cut off by the Ouse Fault. Pikes Fault produces major offset (3km) in base of the Burnt Creek with a narrow sliver of Burnt Creek conglomerate extending to the southwest on the east side of the fault. Surprisingly the top of the Burnt Creek Formation is not offset and in the north the fault becomes undetectable where it lies parallel to bedding-in poorly exposed country. Structure of the Sawtooth Group of the two blocks is described first followed by the Burnt Creek Formation.

Glencoe Block:

Ragged Robin Syncline (new name):

The Ragged Robin Syncline has the characteristics of a syncline in which the hinge zone is replaced by a fault sub-parallel to the axial plane of the fold. The position of this axial plane trace can be seen in Plates 1 and 2. The syncline plunges to the north at c.45° and its axial plane would have originally dipped 80° to the east as indicated in a stereographic plot of poles to bedding (*fig. 3.1* (top)). To the east of the major syncline a large anticline is mapped on the slopes of the Lady Range (Plate 1). Throughout the Sawtooth rocks mesoscopic scale open folds occur (*fig. 2.23*) with their axial planes sub-paralleling the major structure. In a number of localities e.g. Benmore Stream (G.R. 925170) and Chaytors Saddle (G.R. 872166), the strike of the Sawtooth beds changes markedly ($\lesssim$60°) within several hundred metres of the contact with Burnt Creek Formation with the beds being folded around usually to the west (anticlockwise). This

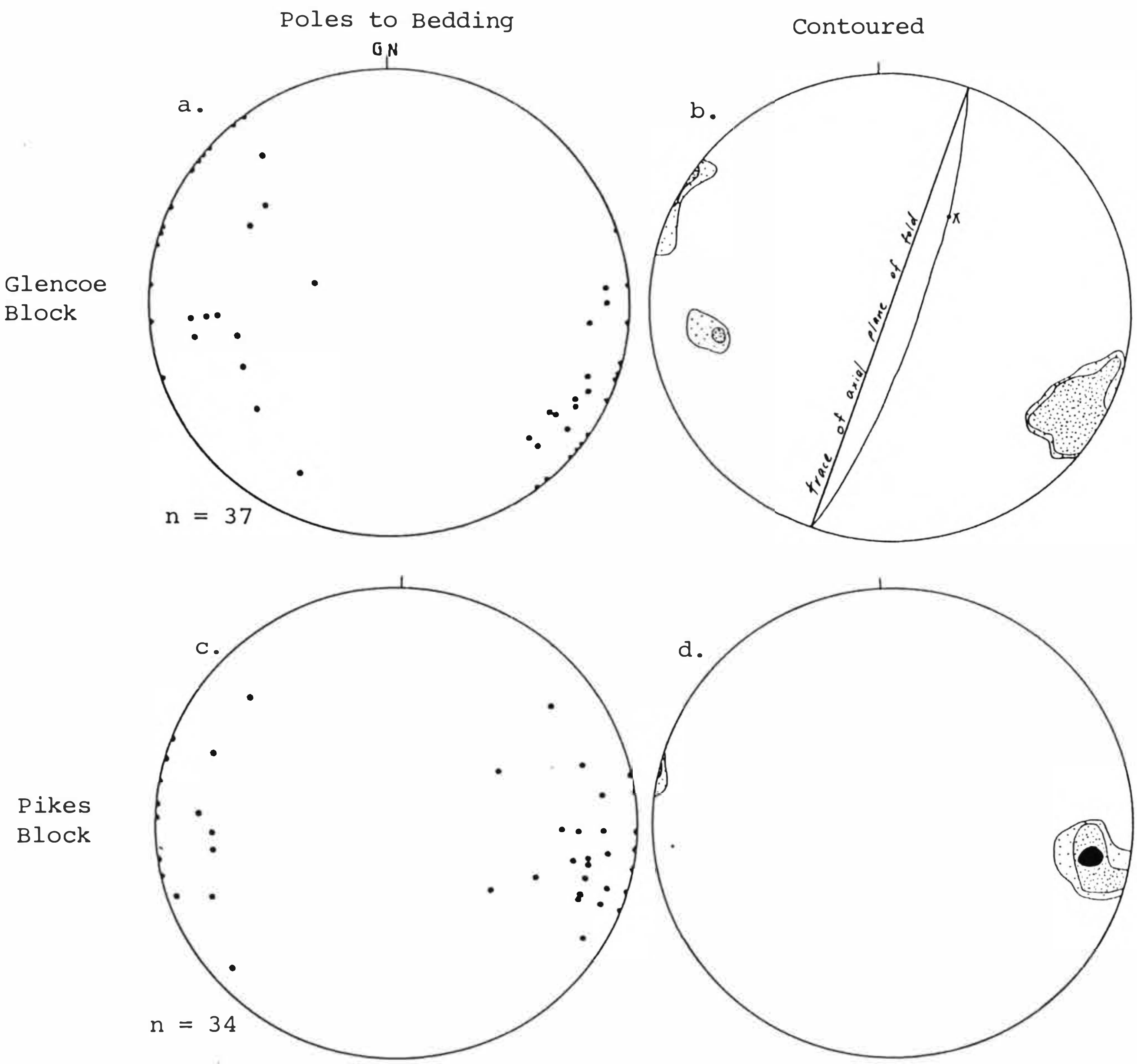


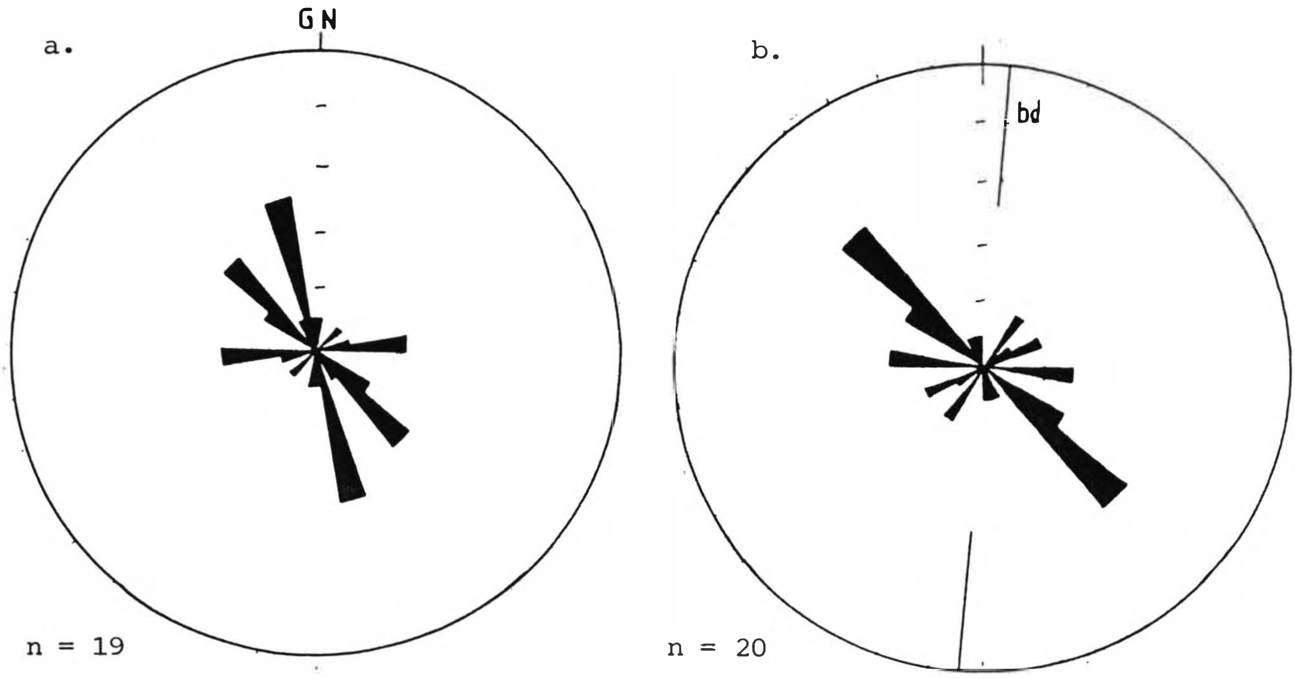
Figure 3.1 Equal area stereograms of Sawtooth Group rocks in Glencoe and Pikes Blocks. a. Poles to bedding Glencoe Block. b. Contours of poles to bedding with axial plane trace and axial direction (π) plotted. c. Poles to bedding Pikes Block. d. Contours of poles to bedding. One limb of fold present. Illustrates sub-parallel nature of major structure in the two blocks. n = number of readings. Contours 5, 4, 3 poles - solid black, dense stiple, spaced stiple respectively.

occurs in localities where the Sawtooth/Burnt Creek contact is faulted (Plate 1) and the basal conglomerate is missing. The folding is thought to be an outcome of movement on these faults. This folding in the Sawtooth is also seen in Pikes Block in Latter's Stream (G.R. 825159).

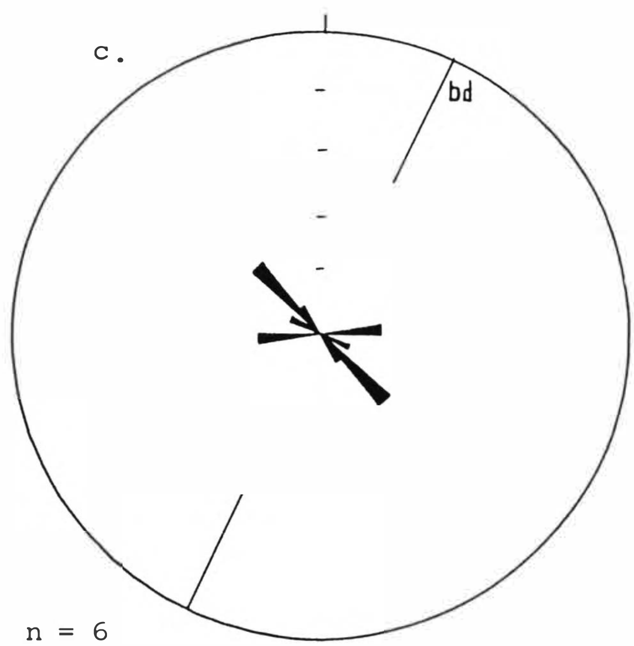
Large faults which parallel the main structure occur in the vicinity of Rag Saddle (G.R. 885161) where crush zones are mapped. These faults pre-date the Burnt Creek Formation. Smaller steeply dipping (70°-90°) faults are widespread in these rocks and are plotted on a rose diagram (*fig. 3.2*). 165°, 135° and 085° are the dominant fault strike directions. Rose diagrams are used to plot fault strike directions because the majority of faults are very steeply dipping (70°-90°) and also often only two dimensional data can be obtained. The diagrams show up the general fault trends. These faults offset the bedding to the extent that on a mesoscopic scale the strike is quite different to what it is overall (megascopic scale). This affect is especially well seen within conglomerate on the western limb on the ridge-top 500m south of Hill 3560' (Plate 1). The western limb has an arcuate form, concave towards the fault axis, due to this faulting. Similar offset shown up in conglomerate is described from the Coverham block (p.109). Bedding parallel shear is widespread in this block, taken up in the less resistant siltstones which are invariably shattered and disrupted. This character of deformation is also seen in Sawtooth of the other blocks.

Detailed mapping suggests that a section of rocks in Kekerengu River (G.R. 915152 to G.R. 912157) which are less deformed and have a younger appearance (e.g. well preserved sedimentary structures developed) than typical Sawtooth Group rocks, are in fact within a conformable sequence of Sawtooth

Glencoe Block Pikes Block



Sawtooth Group



Burnt Creek Formation

Figure 3.2 Rose Diagrams showing distribution of fault strike of steeply dipping faults. a. Sawtooth Group rocks of Glencoe Block. b. Sawtooth Group of Pikes Block c. Burnt Creek Formation at mouth of Ouse Stream (G.R. 802132). n = number of readings. bd = bedding. Plots at 10° intervals. Each graduation = 2 readings.

rocks and represent a part of Sawtooth which has undergone a lower degree of deformation. This is a good example of a point touched on in the Introduction to the chapter (p.83) i.e. that amount and character of deformation in Sawtooth Group or the Coverham Group for that matter, cannot be taken as criteria for separating out formations and groups. This can only be achieved by careful lithological mapping.

Pikes Block:

Sawtooth Group

Marker beds of conglomerate and massive siltstone traceable for 4km+ show up the almost ubiquitously steeply westward dipping and facing structure of the Sawtooth Group of Pikes block. These rocks are thought to represent one limb of a dislocated fold. The axial plane is likely to have been steeply dipping (*fig. 3.1*) like those of Glencoe and Coverham blocks. A large number of meso- and macroscopic folds occur throughout the block and their axial planes are all sub-parallel to the major structure e.g. on 'The Ned' (Plate 1). Steeply dipping (70°-90°) mesoscopic faults widespread throughout the block and especially easily visible in the flysch lithology, are plotted on a rose diagram (*fig. 3.2*). Dominant faulting directions are c.135° and 095°.

Deformation in Burnt Creek Formation:

In both eastern blocks the Burnt Creek Formation is folded along with overlying units into north plunging anticlines which are probably part of a large complex anticlinal structure, the Benmore Anticline (Prebble 1976). The western limb of each anticline is picked out by a sliver of Burnt Creek Formation extending to the southwest between blocks of Sawtooth Group (Plate 1). Eastern limbs are absent except for a sliver of Burnt Creek Formation in Glencoe Stream (G.R. 917134). The anticlines have c.010° trending axial traces, sub-vertical axial planes and plunge c.60° to the north northeast. This deformation overprinted the already deformed

Sawtooth Group although differentiation of these younger structures from the earlier ones is difficult due to the intensity of the Sawtooth deformation. It is likely that some of the earlier structures were reactivated.

Burnt Creek Formation adjacent to the Pikes and Ouse Faults is highly disrupted due to movement on these faults. Tight, steeply north and south plunging mesoscopic folds with axial planes sub-parallel to the faults are common (*fig. 3.3*; e.g. G.R. 804142).

In detail, the Burnt Creek beds are intensely normally faulted producing a 'step-like' pattern in the sandstone beds. Fault movement varies between mm's and cm's. The beds appear to have undergone bedding parallel extension causing this normal faulting. *Figure 3.2* shows the dominant fault strike directions at the mouth of Ouse Stream. There is little evidence for this extensional faulting having occurred contemporaneously with deposition i.e. no sand injection structures, boudinage related to extension etc. It is more likely to have occurred during the folding of the Burnt Creek Formation into northward plunging anticlines.

Pikes Fault (new name):

A small length of the Pikes Fault has previously been recognised in the tributaries of Burnt Creek and named Burnt Creek Fault 2 by Hall (1963). It is renamed Pikes Fault due to its proximity to 'The Pikes'.

Lying between Glencoe and Pikes blocks, the fault extends from an unknown distance south of the Clarence River along a northeasterly trend (030°) passing just a hundred metres east of 'The Pikes', into the Burnt Creek catchment (trend 055°)

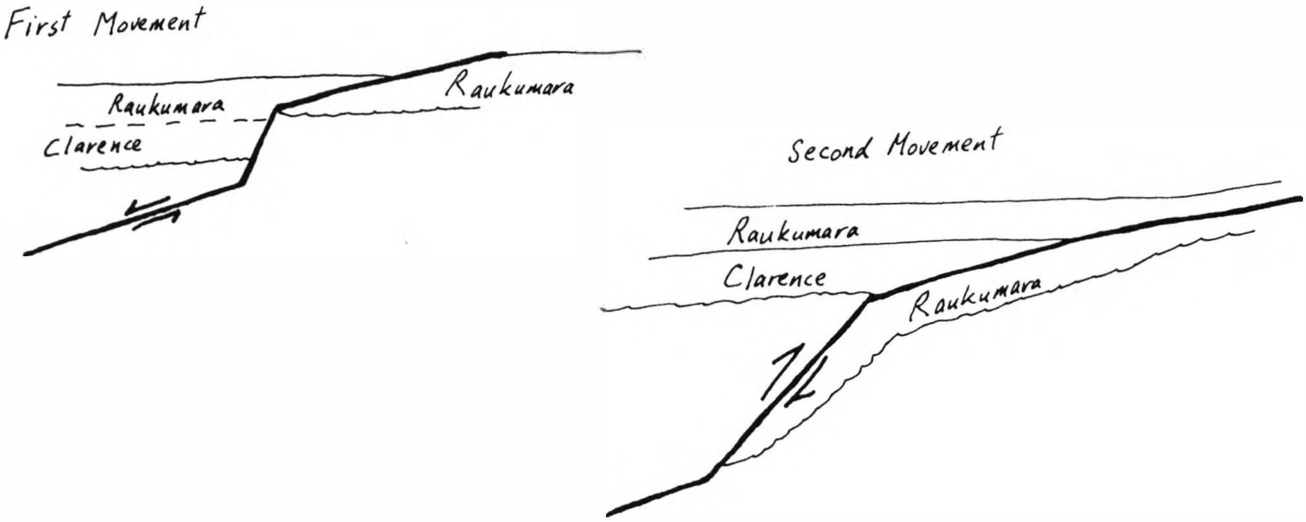
Figure 3.3 Tight, steeply plunging mesoscopic folds in Burnt Creek Formation adjacent to Ouse Fault, Ouse Stream, G.R. 804142.

and then dies out within the Burnt Creek Formation in the head-waters of Kekerengu River (Plates 1,2).

The fault is not exposed but detailed mapping and air-photo interpretation support its existance. A vague trace which suggests a steeply westward dipping axial plane can be seen on the northeastern slopes of 'The Pikes'. The fault is parallel to the basal unconformity and stratification of the Burnt Creek Formation and is also sub-parallel to the Ouse Fault.

Possible pre-Burnt Creek movement on the fault is indicated by the fact that if the base of the Burnt Creek Formation is restored to its original attitude, Sawtooth rocks face in opposite directions across the fault. However opposite facing directions may also be achieved by gentle folds in the Sawtooth.

The fact that the Burnt Creek Formation is thicker and the basal part of it older to the west on Pikes block, suggests initial normal movement on the fault i.e. downthrow to the west. It is likely to have been a listric normal fault for reasons developed in Chapter IV. It appears to have had reverse movement during the later stages of Burnt Creek deposition. This movement thrust Sawtooth rocks of Pikes Block over Burnt Creek of the Glencoe Block (see sketch below). No movement appears to have occurred post-Burnt Creek deposition because the fault does not displace formations younger than Burnt Creek Formation. No evidence of transcurrent movement is present on the fault.



Kekerengu Fault:

This fault is one of the four main dextral transcurrent faults which occur in the northeastern part of the South Island making it the most significant fault in the mapped area. It forms the southeastern boundary of the area but has not been studied in any detail during this project. The east north-easterly trend of the Kekerengu Fault is quite different from that of the Ouse, Pikes and Champagne Faults which are sub-parallel to each other. This suggests that it belongs to a different faulting regime. It is likely that significant movement occurred on this fault prior to the Cenozoic movement suggested by Prebble (1976, 1980) in his detailed history of movement on this fault since the Oligocene. Its configuration is likely to be far more complicated than presented in Plate 1 (Osborne 1981, S. Lamb (pers. comm.), J.D. Bradshaw - pers. comm. - for observations at George Saddle).

Age of Deformation:

Initial deformation of the Sawtooth Group of both Pikes and Glencoe blocks and perhaps also initial movement on the Pikes Fault (see p.89) is pre-Burnt Creek Formation. Burnt Creek is a single continuous formation therefore the main folding of the Sawtooth Group pre-dates the oldest Burnt Creek Formation firm fossil age. This means the initial deformation is of Motuan age.

Further movement on the Pikes Fault must have occurred after Burnt Creek deposition but before Paton deposition i.e. Teratan in age. This fault movement would have also deformed the Burnt Creek rocks adjacent to the fault.

Development of the Benmore Anticline which Prebble (1976) dates at Late Cenozoic and suggests was due to movement on the Kekerengu Fault, further deformed the Burnt Creek Formation and younger beds folding them into north plunging anticlines in the north of the area.

Although it is difficult to distinguish between the structures of each separate event, it is thought that the c.85° x c.135° x 40° fault pattern may be a feature of the later deformation. It is the dominant fault pattern throughout the whole mapped area.

3.2 OUSE FAULT (new name):

Ouse Fault separates Coverham Block from Pikes Block. No Burnt Creek Formation is found west of the fault and no Champagne, Ouse, Wharfe or Swale formations are found to the east of it. This is despite close similarity in ages of these Coverham Group rocks. It is clearly a major structural feature.

A part of this fault was previously named the Wharfe Fault after Wharfe Stream by Hall (1963, 1965). It is here renamed the Ouse Fault because it runs sub-parallel to the much larger Ouse Stream for over 5km southwest of the original mapping, it has been interpreted in a different way during this work, and it is closely associated with origin of the Ouse Anticline.

From the lower reaches of Wharfe Stream where crushed Whangai Formation is exposed at G.R. 843173, the fault trends east north-east (060°-070°) until it dies out in the stream's headwaters. Southwest of Wharfe Stream it can be traced high on the eastern bank of Ouse Stream (trend 040°). Further southwest it crosses Ouse Stream a number of times, firstly at G.R. 812153 where a steeply northwest dipping fault is exposed. It crosses again at G.R. 808147 and also further downstream at G.R. 803143 where it maintains its SW/NE trend and has a vertical fault plane. It continues to the southwest crossing the Clarence River at G.R. 792129 and beyond the boundary of the study area towards the complexly deformed area at the mouth of Mead Stream. The fault between Swale and Nidd, Paton and Whangai Formations at G.R. 839179 is possibly a branch of Ouse Fault. Plates 1 and 2 show the fault's position.

In the lower reaches of Wharfe Stream the fault plane dips c.75NW and on the south bank of the Clarence River (G.R. 792198) at 80NW. In Ouse Stream (G.R. 810150) the sub-vertical fault plane is difficult to see. Although the fault zone rock is crushed it is well indurated and does not appear to have had any recent movement. This is in contrast with a set of younger faults which offset Ouse Fault trending NW/SE (e.g. G.R. 801140) and have soft puggy fault zones. Elsewhere the fault plane is not well exposed but appears to be steeply westward dipping for much of its length.

Sub-horizontal mullion structure in sandstone and rodding equivalent to boudinage if viewed end-on can be found within several metres of the fault in a number of localities suggesting movement sub-parallel to the dip of the fault e.g. in basal Champagne Member in Ouse Stream at G.R. 812153, and in Burnt Creek Formation in Wharfe Stream (G.R. 844173). Further evidence for vertical movement is indicated by the presence of small open to tight folds with highly variable plunge which are developed near the fault in the upper part of Burnt Creek in Ouse and Latter's Streams e.g. Ouse Stream (G.R. 812153). These are consistent with sheath folds which develop in thrust zones perpendicular to the transport direction and are progressively rotated during movement. Motuan Ouse Member rocks are faulted over the top of Raukumara age Burnt Creek rocks in Wharfe and Latter's Streams supporting reverse movement.

Successions on opposite sides of the fault in Ouse Stream young towards each other. The fault cuts out more and more of lower Champagne Member towards the southwest until only a sliver of lower Champagne Member is left between the Sawtooth core and Burnt Creek. This suggests displacement on the fault increases to the southwest. The change in character of the fault is sympathetic with change in plunge of the Ouse Anticline.

The trace of the fault is sub-parallel to the basal unconformity and stratification of the Burnt Creek rocks. In addition the parallel slice of Burnt Creek maintains a uniform thickness of approximately 500km for 9km+. Present structural relationships suggest high angle reverse movement, however the bedding parallel character is consistent with origin as a low angle thrust. Movement is taken up primarily on the main fault plane but also by sub-parallel bedding shears adjacent to the Ouse Fault trace.

The Ouse Fault has a similar geometry and a similar relationship in the Sawtooth rocks to the Pikes Fault (p.89). The Pikes Fault is thought to have initially been a listric normal fault. Likewise the very similar Ouse Fault may have had an early normal phase of faulting. Coverham Group Motuan - Ngaterian sediments are thicker on the western side which would be the down-thrown side if normal faulting occurred.

If the Sawtooth rocks on either side of the fault are restored to their original pre-Coverham Group attitudes, a difference in facing direction is apparent suggesting either pre-Coverham Group movement on the Ouse Fault, or the presence of large gentle folds with several kilometres wavelength in the pre-Coverham Group Sawtooth rocks. The main phase of movement probably occurred during late Raukumara - Mata Series. The nature of the fault plane in Ouse Stream described previously suggests that there has been no Kaikoura movement and there is no evidence for Quaternary movement.

It seems likely that the rocks on each side of the fault were juxtaposed from some distance apart (kilometres) by low angle reverse fault movement. There is no evidence to support a large displacement due to transcurrent movement. Paton Sandstone is the first formation found on both sides of the fault. This is overlain by Whangai Formation and thick Amuri Limestone.

3.3 COVERHAM BLOCK

In the Coverham Block structure is dominated by the partly horizontal, partly north plunging Ouse Anticline which folds Sawtooth and overlying Coverham Group rocks. It is clear from the several localities showing angular unconformity between the two Groups, that the Sawtooth was initially deformed prior to the formation of the Ouse Anticline, however the geometry of this early deformation is difficult to unravel having been masked by the pervasive effects of the subsequent Ouse Anticline deformation. This pre-Coverham Group deformation of the Sawtooth rocks is likely to have been caused either by an early phase of tectonism or by submarine gravity sliding forming large slump folds. In the Champagne Stream area it is clear that the Sawtooth Group rocks were folded along with the Coverham Group rocks into the Ouse Anticline, however further to the southwest along the axial trace of the fold (i.e. G.R. 774119) the structure of the Sawtooth is highly complex and does not show a simple anticlinal structure.

Mesoscopic folds with sub-vertical axial planes sub-parallel to the Ouse Anticline axial plane occur sporadically throughout the Sawtooth rocks. Steeply dipping (70°-90°) normal faults due to extensional effects with movement from cm's-m's are ubiquitous throughout the area. Dominant faulting directions are c.300° and 090°. In the massive siltstone lithology, attitudes tend to be confused due to the high degree of deformation. In general, sandstone beds remain rigid while the thin bedded and especially the massive siltstone undergoes intense deformation to form steeply plunging mesoscopic folds and 'broken formation'. This is typical of all of the Sawtooth Group.

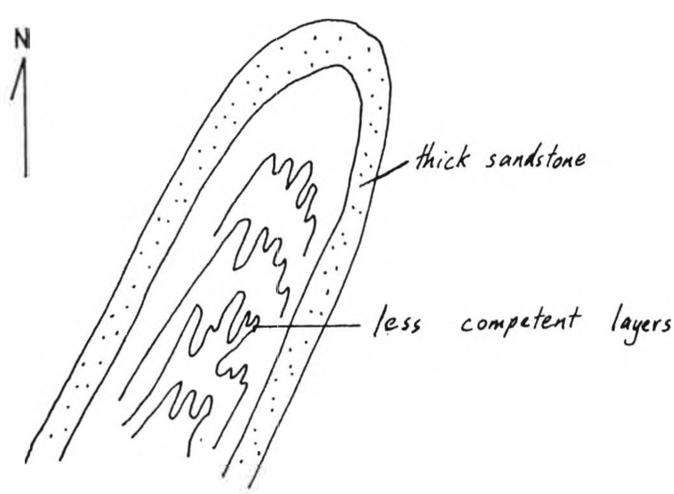
In terms of relative deformation, Sawtooth Group is least deformed in Pikes Block and most deformed in Coverham Block.

Ouse Anticline (new name):

Ouse Anticline is a new name for this major structural feature, a small part of which has been previously recognised by Hall (1963). The anticline takes its name from Ouse Stream. The axial trace swings from trending c.35° in the southwest to c.45° near Wharfe Stream (Plate 1).

The anticline is tight with a steeply westward dipping axial plane and has variable plunge ranging from sub-horizontal in Champagne Stream to 60°NE in the region of Ouse-Swale Streams junction. The variation in plunge may be due to thrusting and/or to differential growth of the fold i.e. bulging middle part of fold. Most of the eastern limb is missing, cut off by the Ouse Fault. Poles to bedding are plotted in *fig. 3.4* and three-dimensional configuration and plan-view sketches of the anticline appear in *fig. 3.5*. The crumpled, folded and buckled nature of the less competent fine grained lithologies in the core of the fold e.g. in the vicinity of G.R. 785135 and G.R. 806156, may be due to the tightness of the anticline (Plate 1) and the fact that thick sandstones seem to be concentrated away from the core on the limbs of the fold. Ramsay (1967, p.415-421) discusses this type of effect.

i.e.

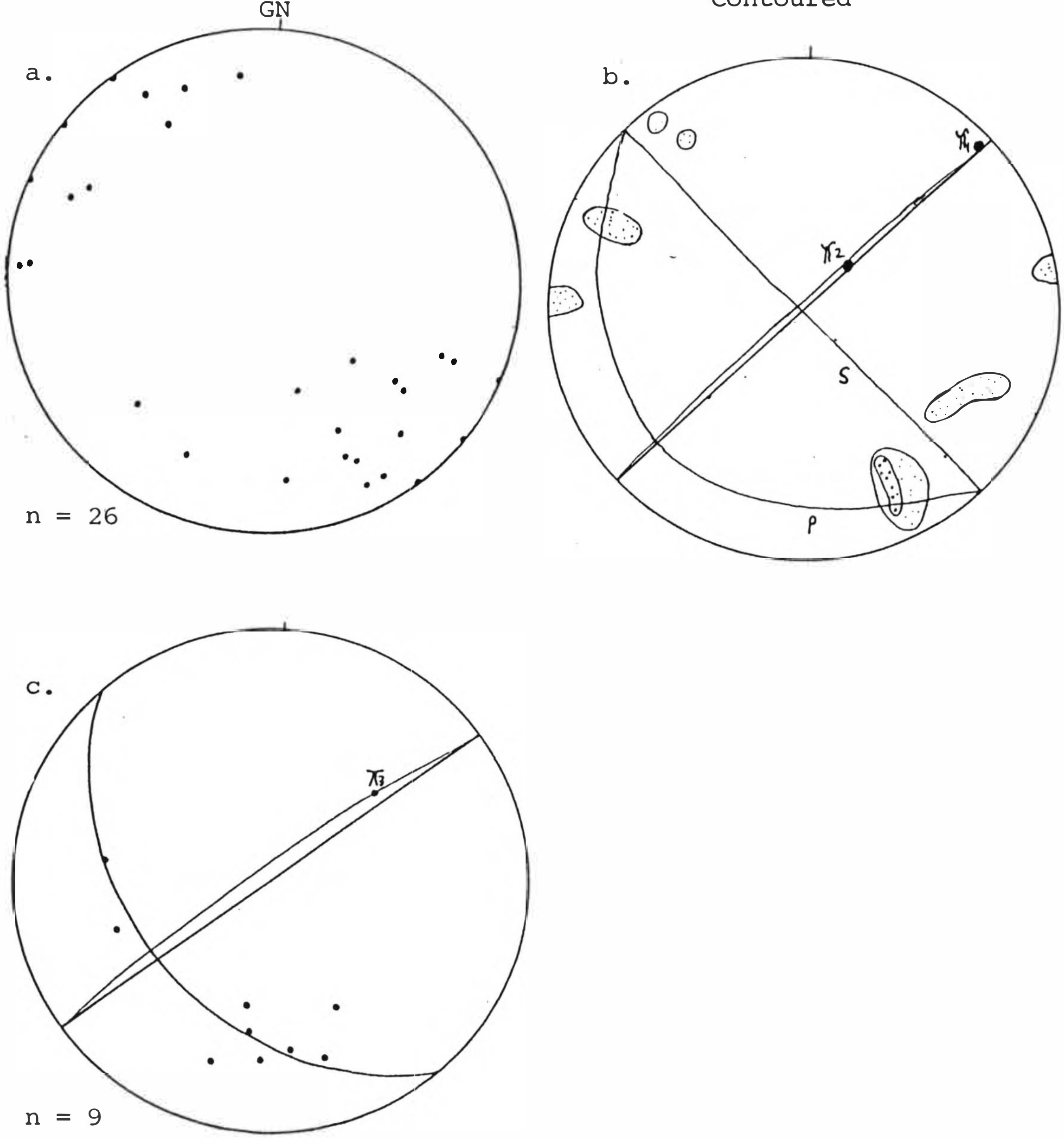


COVERHAM BLOCK

Poles to Bedding

Contoured

Ouse
Anticline
Sawtooth
and
Champagne
rocks



Ouse
Anticline
Wharfe
Member

Figure 3.4 Equal area stereograms of Coverham Block rocks. a. poles to bedding of Sawtooth Group and Coverham Member rocks of Ouse Anticline structure. b. contours of poles to bedding with axial directions of sub-horizontal(s) portion(γ_1) and plunging(p) portion (γ_2). Axial plane traces of the fold and girdles plotted. c. poles to bedding, axial direction (γ_3) and axial trace for Ouse Anticline in Wharfe Member. n = number of readings; contours 4,3 poles - dense stiple, spaced stiple respectively.

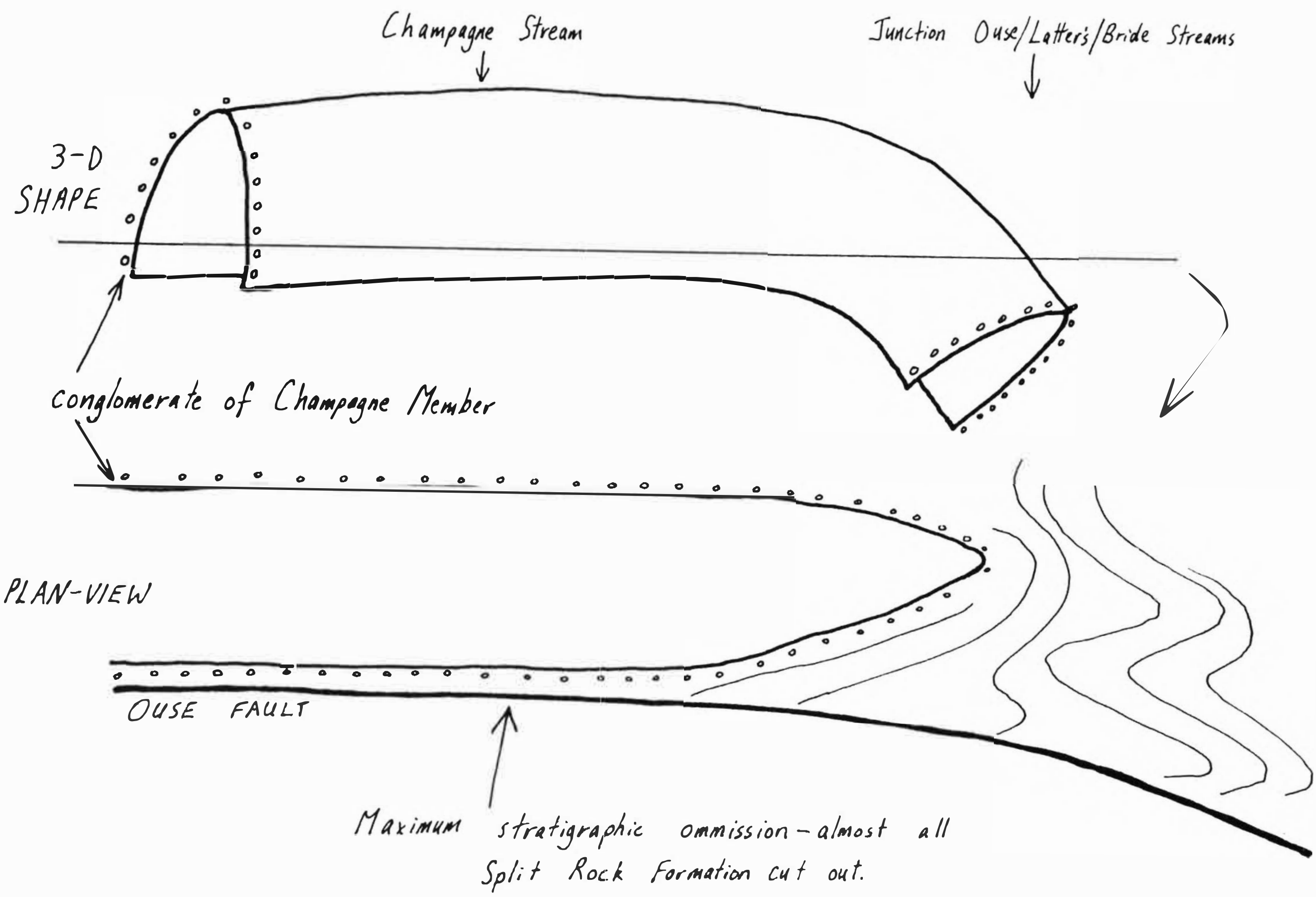


Fig. 3.5: Sketch of 3-D Shape and Plan of Ouse Anticline, Coverham Block.

The anticline has a convergently fanning fracture cleavage discussed on p.104.

The Ouse Anticline formed in response to compression in what is now a southeast/northwest direction. The axial plane is sub-parallel to the Ouse and Champagne Faults and the anticline is believed to be associated with their development.

The unconformity in Ouse Stream (G.R. 817164) between the lower part of the Champagne Member and the Ouse Member and the fact that the Champagne Fault which is thought to have developed concurrently terminates at the base of Ouse Member, suggests that the anticline has had two phases of development, the first before deposition of Ouse Member (folding Sawtooth and lower part of Champagne Member) and the second post deposition of Wharfe and perhaps Swale Members (folding Sawtooth, Champagne, Ouse, Wharfe and perhaps younger formations). This younger part of the fold can be seen in Wharfe Stream folding the Wharfe Sandstone. A complementary syncline has formed just to the east of the main anticline here and a further anticline is found further east at the eastern extent of Wharfe Sandstone. Growth of the fold was therefore progressive. Much growth must post-date Burnt Creek Formation.

Down Ouse Stream near the mouth of Champagne Stream (G.R. 803146), another anticline within Champagne Member rocks has been identified. This subsidiary anticline appears to have an identical configuration to the Ouse Anticline with variable plunge from sub-horizontal at G.R. 790140 to c.60°NE at G.R. 803146. Close proximity and parallelism of this fault bounded anticline to the Ouse Fault suggests that it is intimately related to movement on the fault. It is thought to represent buckling of the beds as Champagne Member rocks were thrust over Burnt Creek rocks (Plate 3, A-B). Folds in Coverham Group rocks immediately west of the major faults are characteristic of the study area: e.g. west of Champagne Fault at

G.R. 791160; west of unnamed fault at G.R. 795173.

Deformation in Split Rock Formation:

Meso- and microscopic structural features of Champagne, Ouse and Wharfe Members of Split Rock Formation have developed due to the growth of the Ouse Anticline and to a pervasive extensional regime both of which deformed the beds penecontemporaneously with deposition. A later compressional regime further affected these beds. At a mesoscopic scale, bedding parallel extension has produced a distinctive normal fault pattern. The pattern of microfaulting is more complex.

Evidence of extension is not surprising, and was predicted by Laird (1980) to occur in mid-Cretaceous times. However large scale compressional structures are also common. It is important to be able to relate the compressional and extensional type structures to each other and to the geological setting within which they occur, hence a detailed study of the deformation was undertaken. Syn-sedimentary deformation has been described in Chapter II within the sections on description, p.22 and p.28. It is apparent that many of the mud injection features occurred penecontemporaneously with early microfaulting e.g. mud has injected along microfaults in places (e.g. Champagne Member in Ouse Stream).

Champagne Member:

Deformation of sandstone beds which are folded around the Ouse Anticline in the lower part of Champagne Member as already discussed (p.98), ranges from minor variations in bed thickness (*fig. 3.6*) to disruption so severe that beds cannot be traced for any distance across the outcrop (*fig. 2.8*). The less deformed parts occur in sandstone dominated lithofacies and display boudinage (*figs. 3.6, 2.11*) and intense meso- and microfaulting (*fig. 3.7*). Mud has in many places injected along microfault planes. The sandstones of the more disrupted

Figure 3.6 Boudinaged sandstones in Champagne Member, Split Rock Formation, Ouse Stream gorge (G.R. 817163). Hammer = 33cm long.

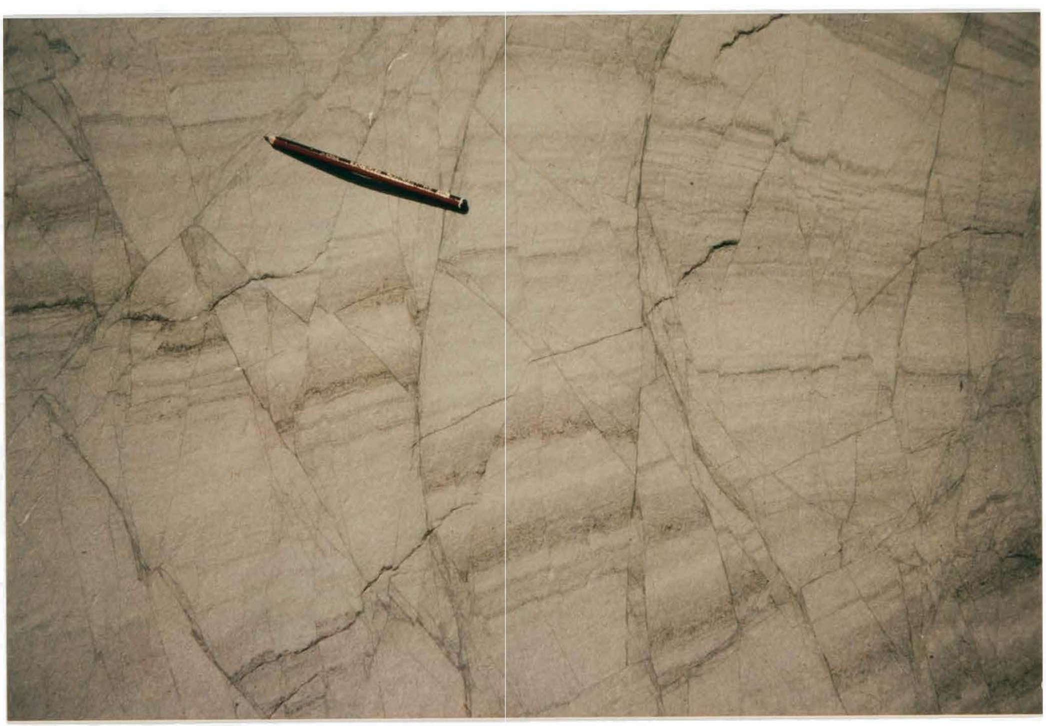


Figure 3.7 Typical faulting in Champagne Member, Split Rock Formation, Ouse Stream gorge (G.R. 817163). Most of faulting is normal. Pencil is 16cm long.

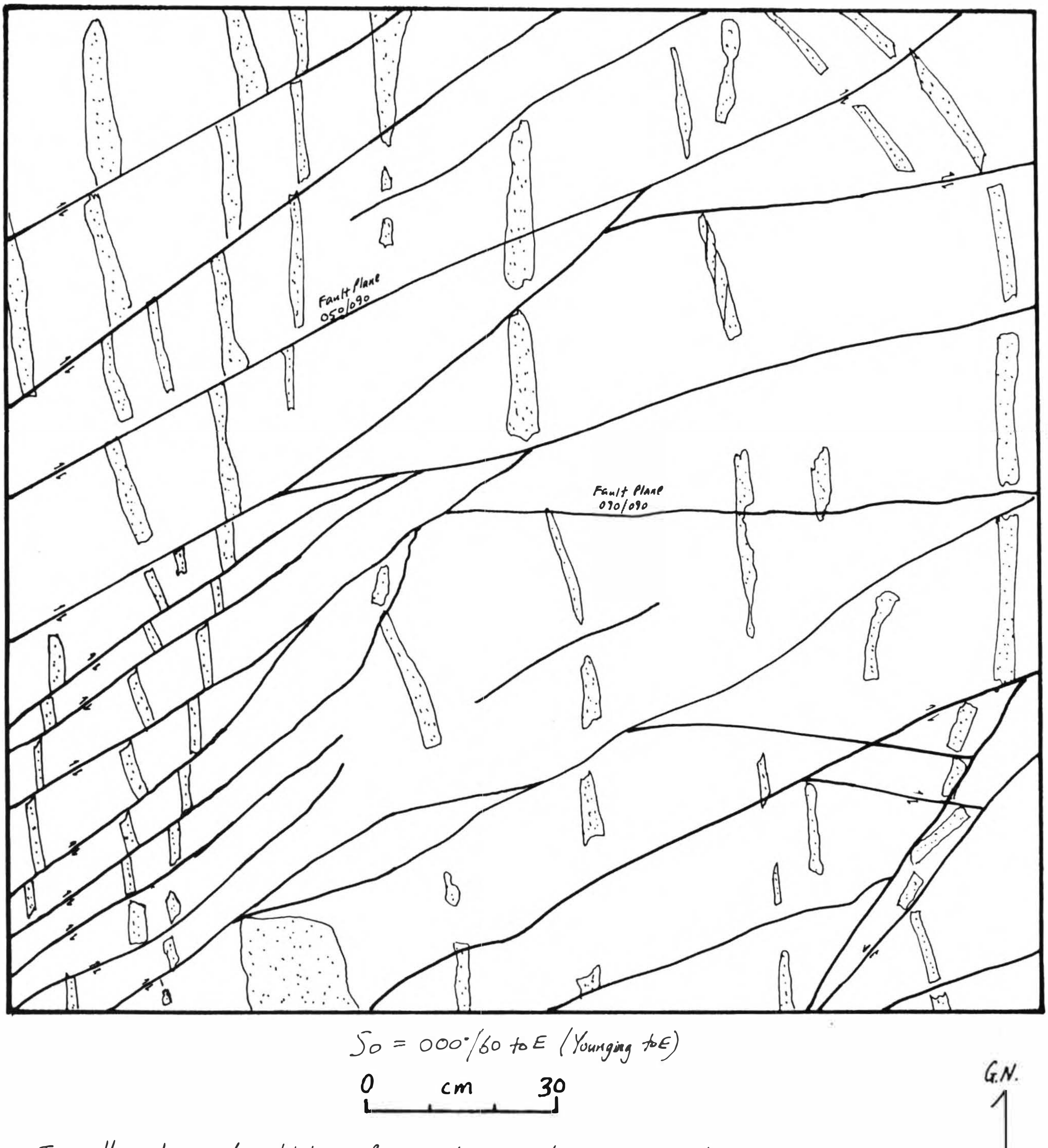
part occur in a siltstone dominated lithofacies which resembles 'broken formation'. Individual sandstone beds are disrupted by mainly normal faulting to form shear losenges/ asymmetric boudins and boudinage structures, yet still maintain gross parallelism (*fig. 2.8*, p.28). Mesoscopic steeply plunging tight folds are also common. Some might call the unit a mélange (cf. Cowan 1985) however because gross stratigraphy is still recognisable I prefer 'broken formation'. The siltstone in this lithofacies shows a faint cleavage. *Figure 3.8* is a detailed sketch of mesoscopic deformation in one of the least deformed parts of this 'broken formation' and shows the dominance of normal faulting. Rose diagrams showing fault strike directions for this locality and two other localities around the anticline are displayed in *fig. 3.9*. These are similar to the expected pattern for fracture cleavage around an anticline (Ramsay 1967, fig. 7.68, p.403). The sandstone dominated unit conformably overlies the siltstone dominated 'broken formation' in Ouse Stream gorge (see Plate 1 and measured section, *fig. 2.3*, p.21).

The shear losenge, boudinage and microfault structures are interrelated and probably formed contemporaneously with the Ouse Anticline. Cleavage type shear is superimposed on boudinage type extension producing shear losenges. The numerous microfaults are due to this diffuse extension (*fig. 3.10*). Ramsay (1967, p.403-411) discusses the development of fracture cleavage during folding of interbedded competent/incompetent layers as is the case here.

It is apparent that deformation varies with lithology in this member, i.e. mud dominated sequences are more deformed than sand dominated sequences. Studies of this type of deformation have been undertaken by Lash (1985). He suggests that the state of compaction during deposition and accumulation

Figure 3.8

Detailed structure of Champagne Member, Ouse Stream (G.R. 816162): Plan View. Sketch.



Typically losenged blebs of sandstone along a vague line.
Faulting extensive and often concealed in finer sandy siltstone beds between.
This diagram is in one of the least deformed areas of Champagne Mbr. (lower part).
More usually it is difficult to follow any particular sandstone bed for more than 1m.
'Matrix' between sandstone beds is sandy siltstone which is completely shattered and crushed to the extent that it is difficult to pick up the faults.
Faulting is generally 'normal'. Dominant faulting with axial plane = 050/090, also strong faulting at 090/090. These beds constitute 'broken formation'.

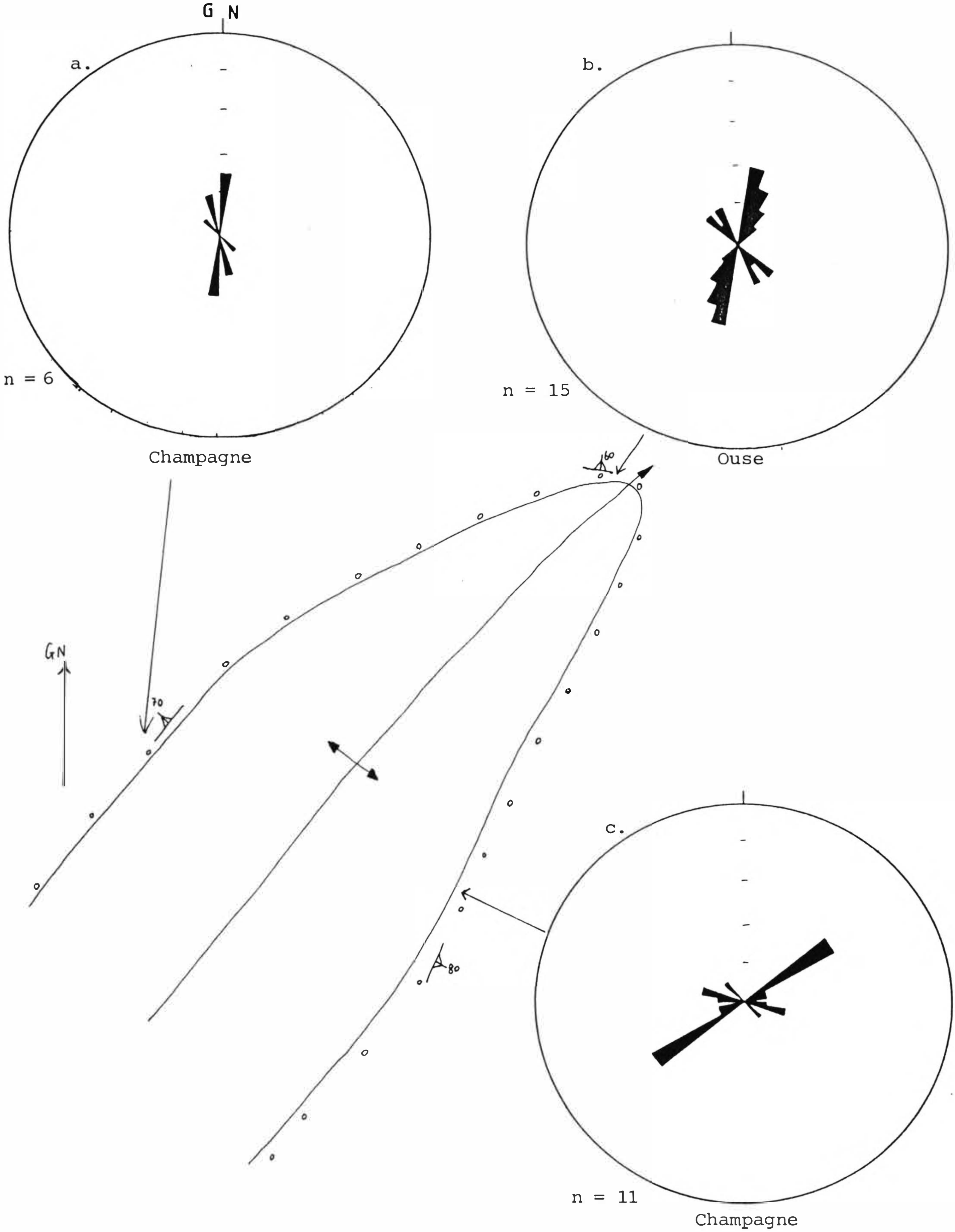


Figure 3.9 Rose diagrams showing distributions of fault strikes in three localities around the Ouse Anticline (sketched); two in Champagne Member (a., c.) and one in Ouse Member (b.). n = number of readings. Plots at 10° intervals. Each graduation = 1 reading.

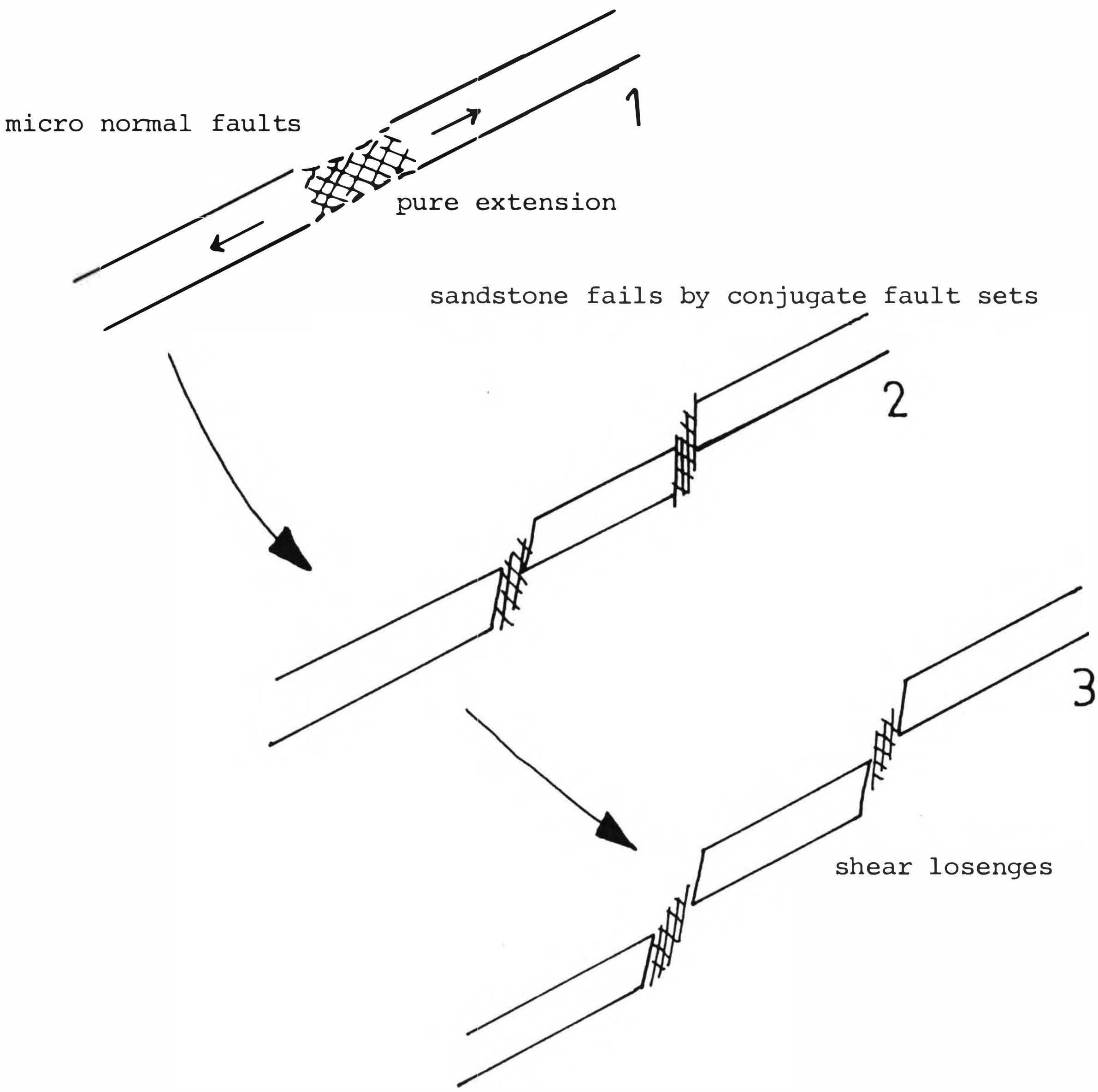


Figure 3.10 Sketch of the development of shear losenges by extension. Diffuse extension also occurs by microfaulting within sandstone losenges.

rates of the sediments may add to variable deformation in different lithologies. Rapidly accumulating sediments are likely to have high pore fluid content. Fine sediments with high pore fluid are likely to deform more rapidly than those without. Lash (1985, fig. 15, p.1176) illustrates a mechanism for differential deformation of sandstone dominated vs. mudstone dominated lithologies in a rapidly accumulated sequence which had a high pore fluid content. In this figure (op. cit.) sand dominated units act essentially as rigid bodies whereas mud dominated units show a high degree of deformation to the extent of forming 'broken formation'. Work by Bray and Karig (1985) and Carson et. al. (1982) suggests that rapid dewatering of sediments with high pore fluid pressures can often lead to striking effects. Localised zones of strong dewatering are associated with zones of intense shear. Generally, dewatering is thought to occur through processes of intergranular permeability, fluid flow component in dewatering veins, fracture permeability and diapiric structures.

This work is relevant to the Champagne Formation because these sediments are thought to have accumulated rapidly with high fluid content and been deformed contemporaneously with accumulation. Fracture cleavage, zones of intense shear, veining, diapiric structures, mud injection structures and microfaulting seen in Ouse Stream within the Champagne Formation may be due to processes described by the above workers.

As an example of shear losenge development, detailed mapping indicates that the geometry of the basal conglomerate of Champagne Member may consist of a series of losenges or end-on diamonds of conglomerate rather than a strictly bedded unit. This is in response to the intense deformation and normal faulting (e.g. *fig. 3.11*).

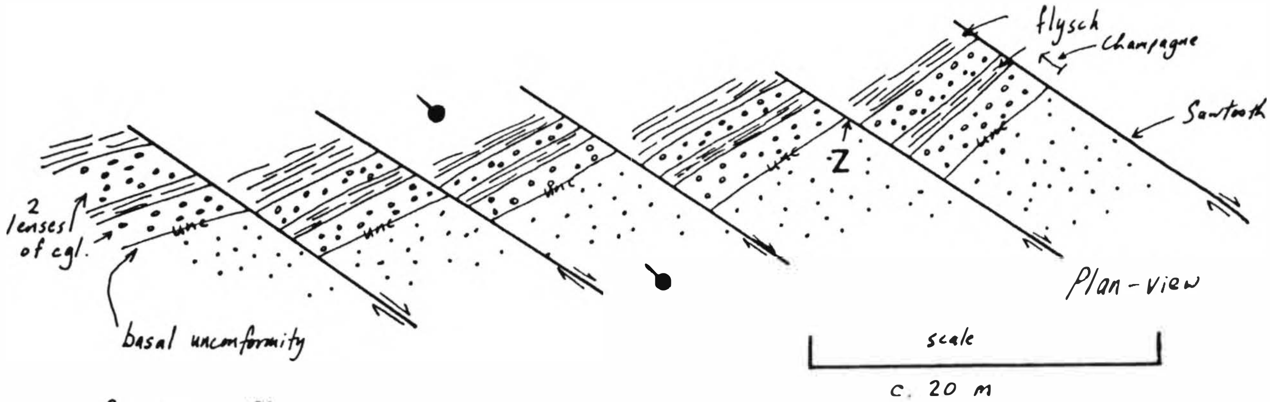


fig. 3.11 : Plan-view sketch of basal contact of Champagne Member (G.R. 813155).

A consequence of this pattern is to have Sawtooth Group in fault contact against Champagne flysch locally with the basal Champagne conglomerate faulted out e.g. at z in *fig. 3.11*.

Other structural features of the Champagne Member include a younger set of faults which strike at c.090° and 130° and have soft puggy fault zones and sub-vertical fault planes. Moderately plunging open and tighter box-folds are common in the upper part of Champagne Member e.g. Mead Stream, G.R. 772146, (*fig. 2.4*, p.23). These folds have been formed by a later compressional regime which developed in what is now a c.NW/SE direction i.e. perpendicular to strike. The beds have also undergone bedding parallel extension. This extension is likely to be due to further growth of the Ouse Anticline.

Similar styles of deformation in similar lithologies makes distinction of Sawtooth and Split Rock in Ouse Stream difficult e.g. at G.R. 812156.

Ouse Member:

Ouse Member, not having been affected by the initial phase of formation of the Ouse Anticline, is more coherent and has a lower intensity of deformation than Champagne Member. For instance thickness of sandstone beds does not vary and they can easily be traced across outcrops. This difference is illustrated by comparing *figs. 3.8* and *3.12*, where the sketches are of average deformation in comparative lithologies for each member. Although more coherent than those of the Champagne, Ouse rocks again show layer parallel extension with many normal faults trending 020°. Minor faulting trending 130°-150° appears to post-date the 020° pattern. Faults generally exhibit sub-vertical fault planes which often have calcite veining infilling them.

Ouse sandstones do not exhibit boudinage structures.

Fig. 3.12 illustrates well the difference between megascopic scale strike and mesoscopic scale strike in Ouse Member (previously discussed p.86).

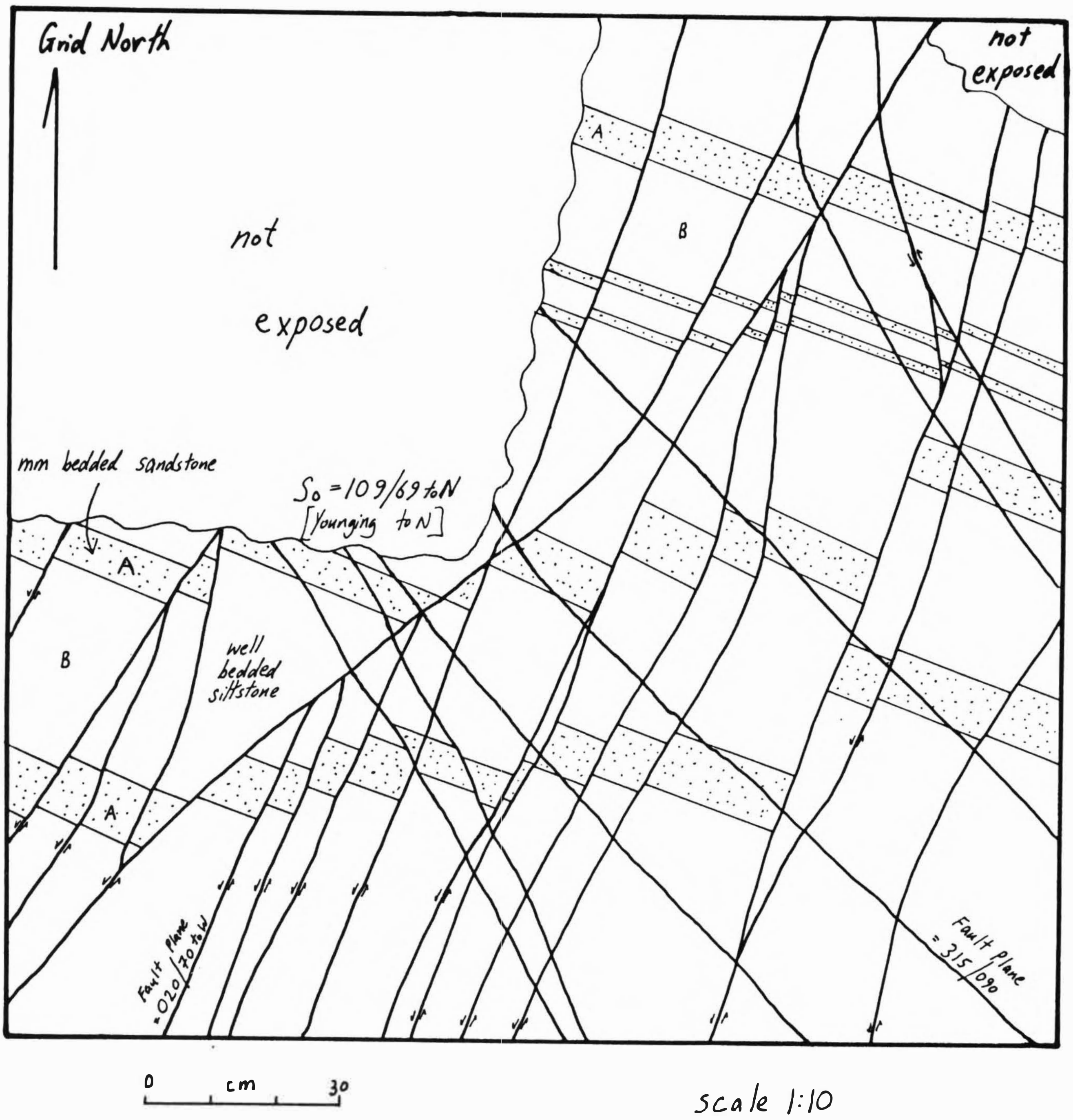
Wharfe Member:

Like Ouse Member, Wharfe Sandstone beds do not vary in thickness and can be traced for long distances. The beds generally dip moderately to the north apart from in the vicinity of Wharfe Stream gorge where they are tightly folded into the Ouse Anticline and two other folds nearby to the east (see p.101).

Once again step-faulting is predominately normal and is due to the beds being deposited during or shortly before a phase of extension. There is good evidence for deformation pene-contemporaneous with deposition (see Chapter II, p.36). A later compressional phase operating in what is now a southeast/north-west direction, folded the beds into a number of northeast plunging folds, poles to bedding for which are plotted in *fig. 3.4*, p.99.

In comparison with the thick m-bedded sandstones of Champagne Member in Ouse Gorge, Wharfe Member sandstones show a higher

Figure 3.12.
Detailed structure of Ouse Member, Ouse Stream (G.R. 818166): Plan View Sketch.



A: Sandstone beds: mm bedded white sand layers interbedded with dark grey siltstone; with occassional climbing ripple lamination and rare convoluted bedding.

B: Siltstone beds: dark grey well bedded siltstone.

Fault set ≃020° strike is dominant. Faulting is normal.

degree of soft sediment deformation and more coherent bedding. In addition, the Wharfe sandstones have a lesser degree of mesoscopic faulting than the Champagne sandstones. For example, one can find an area of $1m^2$ devoid of any faulting in Wharfe Sandstone but this is impossible in the Ouse Stream Champagne sandstones which often display over 200 faults in a comparable area.

In summary, cleavage type shear superimposed on boudinage-like extension formed shear losenge and boudinage structures in the lower part of Champagne Member. Development of these structures is likely to be due to penecontemporaneous growth of the Ouse Anticline. In Ouse Stream Gorge (G.R. 816162), deformation is lithology dependent and often intense with the development of 'broken formation' in the fine grained lithology due probably to the state of compaction and rate of accumulation of the sediments. Additional deformation may be due to movement on the adjacent Ouse Fault. The upper part of Champagne Member along with Ouse and Wharfe Members underwent bedding parallel extension partly contemporaneously with deposition. These rocks subsequently underwent compression in what is now a SE/NW direction. This created a northeastward extension of the Ouse Anticline.

It is important to note that deformation varies within sandstone dominated and siltstone dominated sequences. Also deformation intensity in the Ouse Gorge area is not formation specific.

Champagne Fault (new name):

This newly recognised fault is not exposed but is well marked on aerial photographs and clearly supported by detailed mapping. It can be traced as far north as the base of the Ouse Member (G.R. 809166) and trends at 220°-235° within Champagne

Member across Mead Stream and to the limit of mapping.

Normal fault movement on the Champagne Fault is suggested by the northwestward dipping fault plane showing downthrow on the northwestern side. Another obvious feature of the fault is that it is sub-parallel to the stratification and basal contact of Champagne Member. This suggests that it may have formed contemporaneously with growth of the Ouse Anticline.

The earliest detectable movement on the Champagne Fault, likely to have been contemporaneous with early growth of the Ouse Anticline, is indicated by the termination of the fault at the base of the Ouse Member. Further minor movement may have occurred with continuation of growth of the Ouse Anticline however the fault does not affect Ouse, Wharfe and Swale Members and is thought to simply die out in this northeasterly direction. Movement is likely to have been in the order of hundreds of metres.

It is possible that the Champagne Fault is an old basement fault like Ouse and Pikes Faults to which it is parallel.

Other Faults:

The area in the vicinity of the mouth of Mead Stream has complicated structure which was not completely unravelled during this study. A fault which runs parallel to Gibson Stream, tentatively named Gibson Fault, apparently dextrally offset the Burnt Creek Formation (Plate 1). However this fault does not appear to continue past the base of the Champagne Member further up Mead Stream (G.R. 768130). A crush zone up to 200 metres wide and trending 030° occurs near the mouth of Mead Stream within Sawtooth Group rocks. It does not appear to cross the Gibson Fault therefore predating it. Further work is needed in this region.

A fault within Champagne Member rocks crossing Mead Stream at G.R. 768156 has a c.150m wide crush zone and continues to the southwest and northeast trending 050°-060°. Field mapping indicates that most recent movement on this fault appears to have been either reverse or transcurrent, however it is likely to originally have been a normal fault. Original normal movement is evidenced by younger Champagne Member rocks on the northwestern side of the northwestward dipping fault. Later reverse or transcurrent movement is difficult to prove but is suggested by the sharp northwestern boundary of Ouse Member and dislocation and folding of Ouse and Wharfe Members in Swale Stream near G.R. 808180. Vertical movement is thought to be in the order of tens of metres.

Further upstream, a moderately westward dipping fault is found at the base of the Amuri Limestone (G.R. 765161) although the fault plane is not exposed here (Plate 1). It is likely that the Amuri Limestone acted as a rigid body with respect to the underlying Champagne Member rocks and that minimal normal fault movement occurred on the fault.

Another fault trending north northwest offsets part of Amuri Limestone dextrally at G.R. 818194. This fault runs south into the field area and must post-date Amuri Limestone (see Plate 1).

Age of Deformation:

The Sawtooth Group was deformed prior to deposition of the Split Rock Formation by the earliest ascertainable phase of deformation which occurred in the Early Cretaceous (Lower Clarence or Taitai Series). The Ouse Anticline was initiated during the Motuan along with movement on the Champagne Fault. This early movement deformed the lower part of the Champagne Member. A further phase of growth of the anticline which was also accompanied by movement on the Champagne Fault, deformed the Ouse, Wharfe and perhaps younger formations, probably during the Teratan.

3.4 SUMMARY

Early workers considered the Rangitata Orogeny to represent a single but complex event which deformed the Torlesse rocks of the New Zealand Geosyncline creating a widespread single unconformity between them and the overlying cover rocks (Suggate in Suggate et. al. 1978, p.318). Other workers have stated that sedimentation between the Torlesse and cover is locally continuous (Wellman 1955, Lensen 1962).

Neither of these alternatives are entirely satisfactory. Despite Lensen and Wellman's ideas a truly conformable sequence through the Torlesse/cover contact has never been found. As for a general unconformity, despite one or two unconformities near the contact, there is no single well marked change in detrital mineralogy, sedimentary character etc. consistent with major orogeny, widespread erosion and new sedimentary basins. Changes in metamorphism as expressed in mud rocks are progressive (Montague 1981).

Montague (1981) working on coeval rocks in the Awatere Valley 30km to the west of the study area has suggested that the change from Rangitata to post-Rangitata Orogeny conditions was evolutionary and cannot be fixed to a specific time.

A number of facts and statements arising from the present study can be listed:

1. Presence of major, 2-4km thick, generally westward facing packets of similar sedimentary rocks separated by westward dipping, bedding parallel faults (see cross-sections, Plate 3), which are likely to originally have been listric normal faults and low angle thrusts.

2. These packets comprise Sawtooth Group rocks overlain by Coverham Group rocks with a marked angular unconformity

between them in most localities. Elsewhere this major unconformity is more subtle and overall, it appears to have developed diachronously. Another minor unconformity appears within the Coverham Group at the base of the Ouse Member.

3. The presence of the Ouse Anticline which was growing during the Motuan and perhaps part of the Ngaterian.

4. Presence of different but contemporaneous Coverham Group successions either side of the Ouse Fault; Split Rock Formation to the west and Burnt Creek Formation to the east. These two formations represent localised depositional basins and comprise predominately fine grained rocks and shell-beds which in both cases unconformably overlie the more deformed rocks which are typically more sandy with thick conglomerates and sparse fossils. Although the basins are likely to have been quite separate from each other during deposition, they have since been juxtaposed by movement on the Ouse Fault.

5. Sawtooth Group rocks in each of the three packets have similar Urutawan - Motuan ages. The overlying Coverham Group has similar Motuan - Ngaterian ages on each side of the Ouse Fault except for on the Glencoe Block where the basal Burnt Creek Formation is of Teratan age. There is only a small age difference between Sawtooth and Coverham rocks. The base of the Burnt Creek therefore youngs to the east.

6. Higher deformation intensity occurs immediately adjacent to the major fault zones, to the extent of forming 'broken formation'. In these zones it is extremely difficult to separate rocks of Sawtooth and Coverham Groups due to similar degrees of deformation in the similar lithologies of each.

7. Bedding parallel extension is present in all formations older than the Whangai Shale.

8. Presence of numerous structures formed by compressional tectonics in what is now a northwest/southeast direction.

9. Presence of structures which probably formed due to dewatering of sediments which were deposited with high pore fluid pressure.

10. Presence of a nearby source for probably subduction-related acid igneous volcanic activity which produced andesitic-rhyolitic tuffs.

11. Both the Sawtooth and the Coverham Group rocks contain thick conglomerates consisting of well polished and rounded acid igneous and quartz clasts which appear to be reworked from older conglomerates. Also, Triassic and Jurassic microflora occur in some abundance in the sandstones of the Coverham Group (see Appendix II, p.157) suggesting a component has been reworked from older sedimentary rocks. There is no real change in detrital mineralogy across the Sawtooth/Coverham boundary.

12. Activity on the 3 main faults in the study area - Pikes, Champagne and Ouse, had ceased by Latest Cretaceous time when stability reigned enabling deposition of thick shelf deposits. This stability was disrupted by Miocene Kaikoura Orogeny tectonism.

13. The Torlesse Supergroup is thought by many workers to represent a subduction-related accretionary complex (Blake et. al. 1974, Coombs et. al. 1976, Andrews et. al. 1976, Sporli 1980, Bradshaw et. al. 1981, MacKinnon 1983). The Sawtooth Group either represents or overlies 'younger Torlesse', Pahau sub-terrane (Bradshaw et. al. 1981).

Any model which is suggested to explain the depositional and structural characteristics of this area must be able to accomodate these points. Bradshaw et. al. 1981 consider Pahau sub-terrane rocks to lie in an accretionary prism setting and have their source in similar Torlesse rocks further inland on the prism. In the Kekerengu - Clarence River area there is evidence consistent with this hypothesis. The Sawtooth was laid down in a thick fan deposit as part of or on top of the Pahau sub-terrane accretionary complex, and underwent a phase of deformation (creating unconformity) after which further similar fan sedimentation led to the deposition of Split Rock and Burnt Creek Formations as accretionary slope basin deposits. This scenario is analagous to the present day covergent plate boundary of the eastern North Island. West dipping imbricate thrust faults, growing folds, slope basins containing thick flysch deposits etc. are all reported in the Hawkes Bay area both on and offshore (Lewis 1980, (in press), Pettinga 1982, Pettinga and Lewis 1985).

Intra-Motuan syn-sedimentary growth faulting has recently been reported in the Awatere Valley (Montague 1981, Laird and Lewis 1986). The latter also report an east to northeast deepening mid-Cretaceous paleoslope in the Awatere.

Possible models are discussed in the following chapter.

CHAPTER IV

GEOLOGICAL HISTORY

A number of models can be derived to attempt to explain the characteristics of the study area listed at the end of Chapter III. Reconstructions for the New Zealand region suggest that during the mid-Cretaceous the east (Pacific) facing continental slope had a northwest/southeast or north northwest/ south southeast strike (Bradshaw et. al. 1981, MacKinnon 1983, Walcott 1984). Although the exact amount is controversial, most workers agree that between 25°-65° of clockwise rotation has occurred between the mid-Cretaceous and the present day. For the purposes of this chapter I will assume the sediments were laid down with the slope striking in a northwest/southeast direction - that is with a northeastwards dipping paleoslope.

1. NORMAL FAULTING - SUBMARINE FAN-DELTA DEPOSITION:

Moore and Speden (1979, 1984) present this model for the deposition of coeval sediments in the eastern Wairarapa, east coast North Island. Their model is essentially that presented by Surlyk (1975, 1978) for East Greenland submarine fan-delta sediments. Briefly it has a large normal fault striking northwest/southeast downthrown on the northeastern side. Uplift and erosion within a rising hinterland to the southwest provided a sediment source and block faulting provided a rapidly subsiding basin in which the coarser sediments were deposited adjacent to the hinterland in the deepest water, while finer-grained sediments accumulated in shallower water near the outer margin of the basin (*fig. 4.1*). A pervasive intra-Motuan tectonic event resulted in widespread slumping and associated deformation (Moore and Speden also report an intra-Motuan tectonic event in the eastern Wairarapa). Shelf deposition then took place. The outcome was a submarine unconformity overlain by shelf deposition.

This model is compatible with some data from the Coverham area e.g. Burnt Creek Formation thinning and becoming more finer-

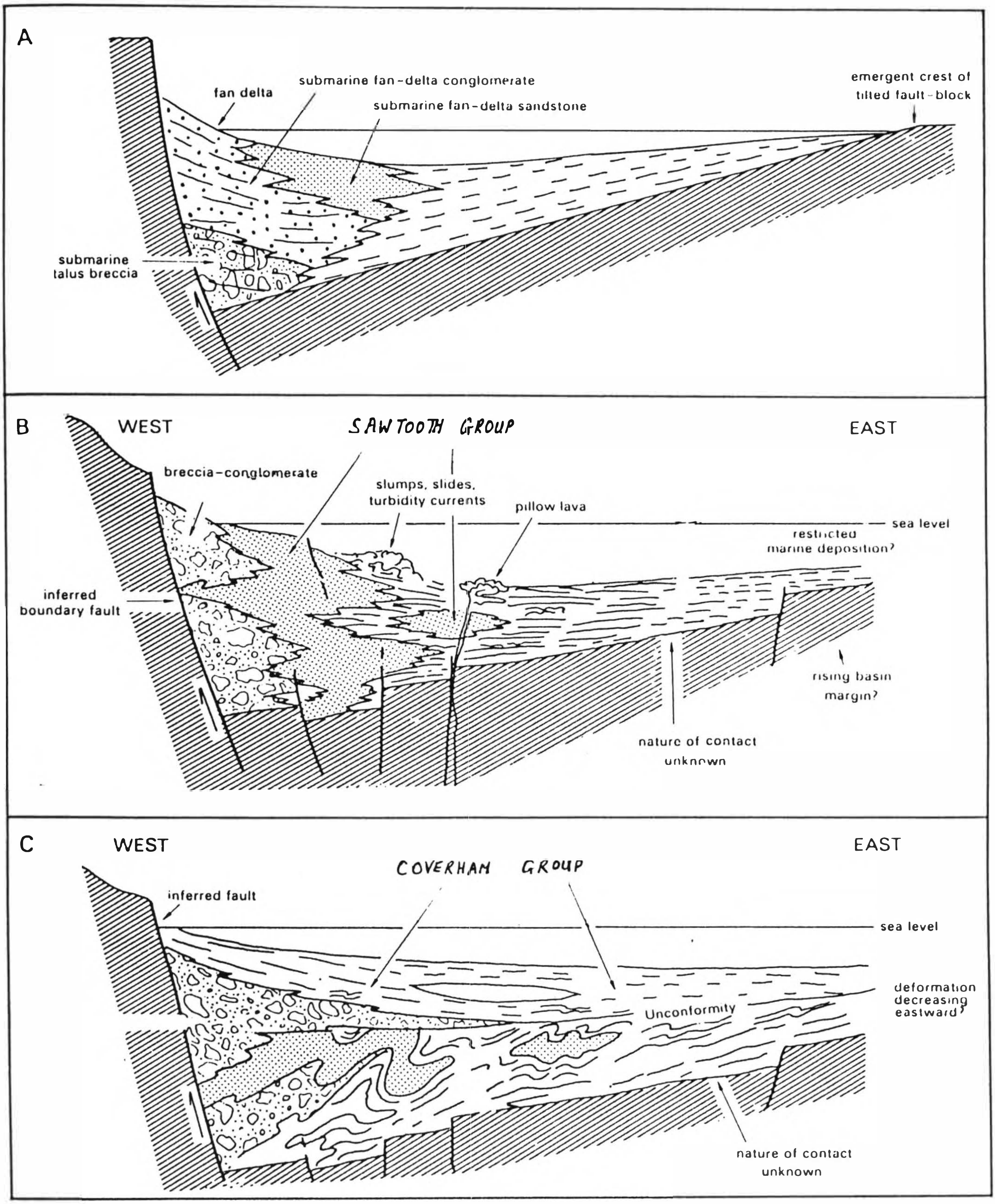


Figure 4.1 Normal faulting - submarine fan-delta deposition: A. Model proposed by Surlyk (1975, 1976) for East Greenland fan-delta sediments. B. Submarine fan--fan-delta model for deposition of Sawtooth Group. C. Inferred environment of deposition for Coverham Group on top of deformed Sawtooth rocks (after Moore and Speden 1984, fig. 48).

grained to the east; a similar intra-Motuan event occurred in the Coverham area; and common mass movement features; however it fails to account for the following: There is no evidence that Sawtooth Group is finer-grained to the east (although only a small part of it has been studied); there is no evidence that either Sawtooth or Coverham Group conglomerates are thicker to the west; the model doesn't easily explain the presence of very low angle thrust faults (e.g. Ouse Fault); the model can't easily explain the presence of different but contemporaneous successions (Split Rock/Burnt Creek) which are likely to have been deposited in nearby but separate basins.

2. SAWTOOTH DERIVED FROM A SOURCE SEAWARD OF THE TRENCH:

This model has Sawtooth sediments being derived from a source seaward of the trench, being rafted in on the downgoing slab and accreted, with Split Rock and Burnt Creek representing slope basin deposits. Moore and Karig (1976) studying the Skikoku subduction zone - S.W. Japan, have identified growing folds similar to the Ouse Anticline at the foot of an accretionary complex with similar fold structures and ponded slope basin deposits which progressively tilt more steeply landward the further they are carried back in the prism (see *figure 4.2*).

There are major drawbacks to this model. Firstly, there is no great difference in detrital mineralogy or composition between the Sawtooth and Split Rock/Burnt Creek rocks which one might expect if they were from different sources. In addition much of the Sawtooth conglomerate appears to be derived from thick conglomerates further up the accretionary prism. Another factor is that the study uncovered no units of oceanic affinity in the Sawtooth i.e. no pillow lavas, chert, pelagic limestone (if the descending slab's sediment thickness is not great these are unlikely to be present anyway). Also, the majority of previous workers agree that the Pahau (Sawtooth) is derived from the up-slope side of the trench arguing that the subduction zone was

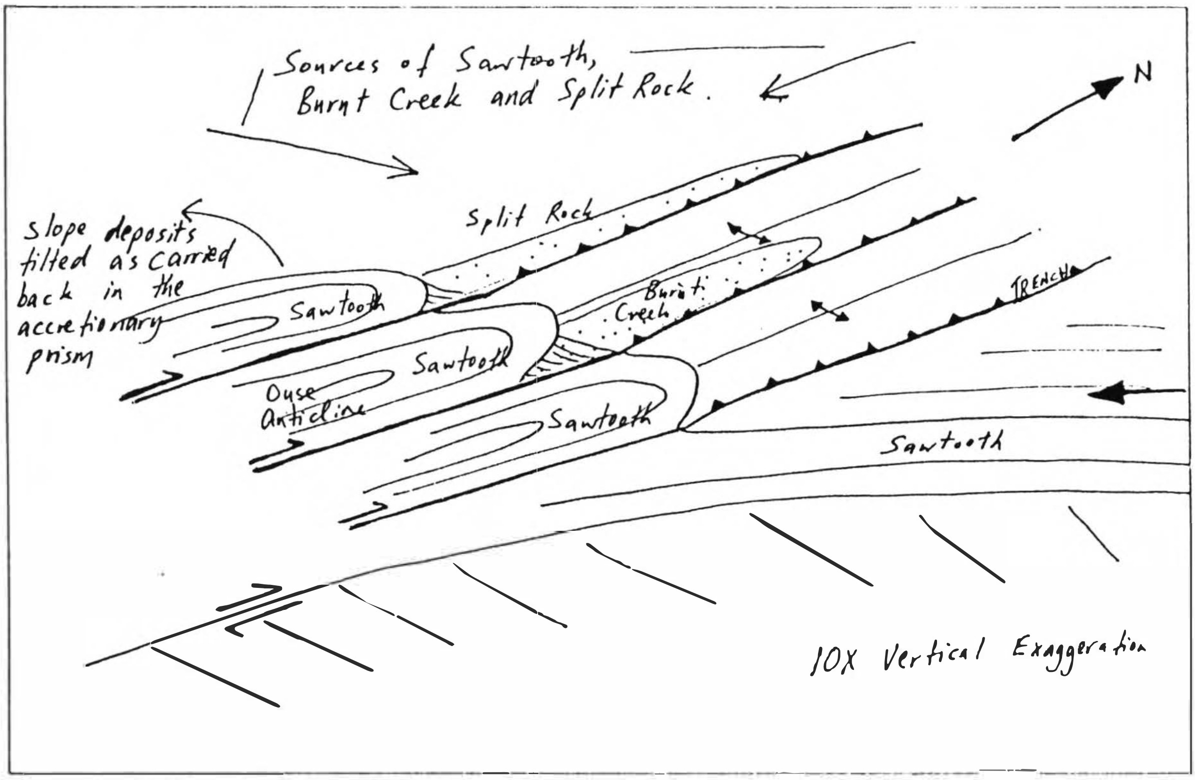


Figure 4.2 Sawtooth derived from a source seaward of the trench.

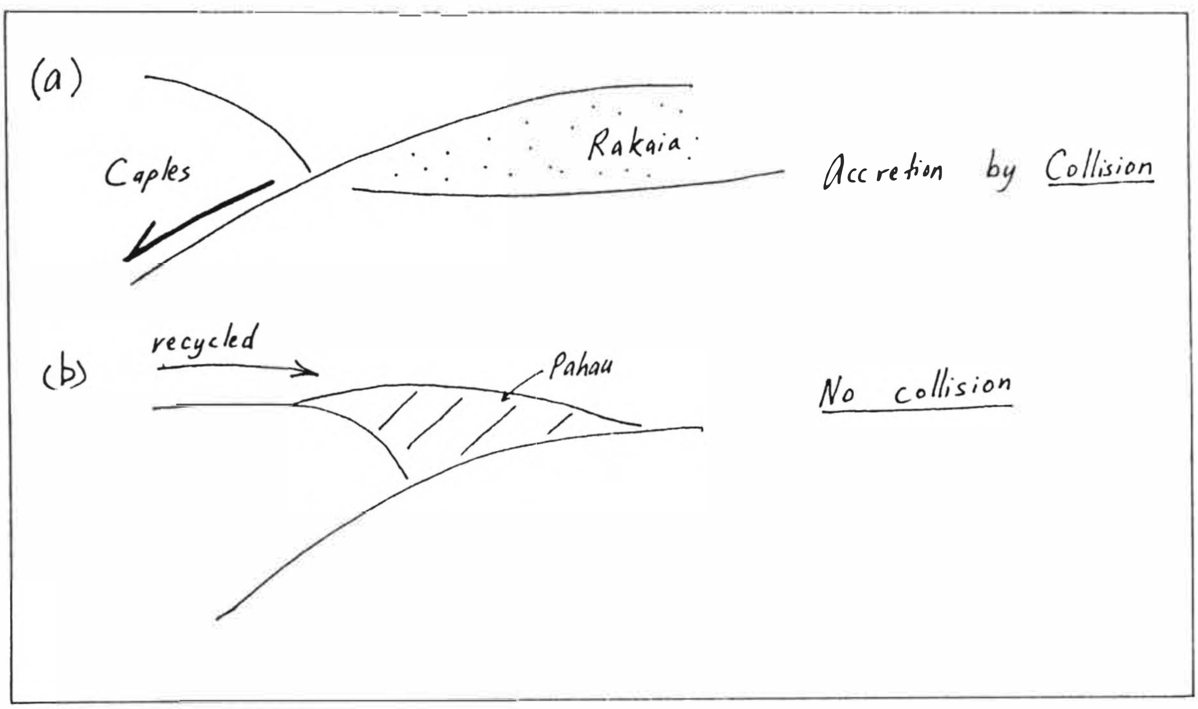


Figure 4.3 Different types of accretion: Rakaia - Pahau.

at a very low angle creating a site for thick and extensive Pahau (Sawtooth) sediment accumulation (see Bradshaw et. al. 1981, MacKinnon 1983).

3. SAWTOOTH SEDIMENTS DERIVED FROM UP-SLOPE DIRECTION, PROGRADING OUT TO FORM SUBMARINE FANS, THEN BEING DEFORMED:

The Pahau Terrane has become part of an accretionary complex due to a different type of accretion than that which recent workers suggest has occurred in the Rakaia Terrane i.e. 'collision' with the Caples Terrane (Bradshaw et. al. 1981) (*fig. 4.3*). Although pillow lavas, cherts and pelagic limestones of oceanic affinity are found in the western part (older Pahau) of the Pahau, the eastern part (younger Pahau) is thought to represent a thick pile of sediments which are recycled partly from Rakaia Terrane rocks and partly from the 'older Pahau'. These sediments were laid down on top of the 'older Pahau' accretionary complex which overlay a very low angle subduction zone (Bradshaw et. al. 1981, MacKinnon 1983). They are now incorporated in a sediment prism which may have undergone processes of accretion (*fig. 4.3*).

This model has up-slope derived Sawtooth sediments being deposited in a submarine fan environment which prograded out over 'older Pahau' accretionary prism sediments. The Sawtooth was deformed by a short-lived intra-Motuan event and Split Rock and Burnt Creek (also up-slope derived) were then deposited in separate slope basins on the deformed surface. This model which incorporates elements of models 1 and 2 (i.e. a seaward prograding submarine fan as in model 1, and slope basin deposits (Split Rock/ Burnt Creek) accumulating in a similar fashion to those in model 2) is more consistent with the data and is developed below.

Korangan - Urutawan - Early Motuan (*fig. 4.4*):

A thick sequence of Sawtooth sediments accumulated on a subsiding northeastwards facing paleoslope. The sediments had a dual source in recycled Rakaia Terrane rocks and older uplifted

Pahau Terrane rocks. Sediment transport was by mass flows down submarine channels cut in the paleoslope sub-perpendicular to the shoreline feeding submarine fans supplemented by sediment introduced parallel to the strike of the paleoslope. This supplementary source may have included fresh volcanic pebbles from a contemporary igneous source. Andesitic-rhyolitic tuff of uncertain derivation (but likely to be subduction-related volcanics) was introduced intermittently throughout the deposition of these beds.

Early Motuan - Early Ngaterian (*fig. 4.5 and 4.9a*):

The Sawtooth Group sediments were highly deformed by a short-lived event during the Motuan. This event may have been a huge submarine slide which moved down the gently seaward dipping paleoslope causing low angle faulting and fold-ridges to develop in the Sawtooth sediments. The Sawtooth sediment packet affected was between 3-4km thick and folds developed would have been gentle open folds with a 2-3km wavelength. Similar huge submarine slides have been reported in present day accretionary slope settings e.g. N.W. Sundra Arc near Burma (see Discussion, p.136).

Alternatively, the faults and folds of the underlying accretionary prism (older Pahau) began to propogate up through the Sawtooth sediment wedge with large faults and folds becoming active.

Once the main movement had ceased, localised erosion occurred and dual source deposition (see above) recommenced with deposition of the Split Rock/Burnt Creek Formations as slope basin deposits. Continued instability within the slide or tectonically active slope created continued faulting and folding of the Sawtooth wedge and the slope basins which were beginning to accumulate between the fold ridges or 'highs'. Normal fault movement began on the Champagne, Pikes and perhaps also Ouse Faults. Erosion of structural highs contributed to the basal Split Rock and Burnt Creek conglomerates. Evidence for this is seen in the highly angular locally derived boulder size clasts in these bimodal conglomerates. This folding and faulting induced the formation of the Ouse Anticline in the mid-Motuan and it continued to grow into the early Ngaterian. The Champagne, Ouse and Wharfe members were laid down in different parts of a single basin on the tectonically active slope. Burnt Creek Formation was laid down concomitantly in a similar but unconnected slope basin nearby which is likely to have been separated from the Split Rock by a fold ridge (structural high) which formed a barrier to down-slope sediment movement (see *fig. 4.5*). This situation is illustrated in the east coast North Island accretionary complex setting where isolated basins separated by structural highs have been forming since the Miocene; e.g. Makara Basin - 20 x 30km area, which is surrounded by zones of highly deformed rocks which were active structural highs during its development (van der Lingen and Pettinga 1980).

Sporadic and decreasing andesitic-rhyolitic volcanic activity continued nearby into the late Motuan.

Ngaterian (*fig. 4.6 and 4.9b*):

Fine-grained sediments (Swale) were deposited over the top of the Ouse and Wharfe members in the Coverham area while further northeast fine-grained Burnt Creek deposition continued. An uplifted inner margin of the slope is indicated by unconformity and Ngaterian coal measures (Warder) found 60km to the south-west in the middle Clarence Valley (Reay 1980) (shallowing in this direction is also reported for coeval rocks in the Awatere Valley (Laird 1980)). Volcanism changed from acid (Urutawan - Motuan) to alkaline in the Ngaterian (e.g. Tapaenuku Volcanic Complex - Nicol 1977) perhaps reflecting a change in tectonic regime from subduction-related volcanism (pre-Ngaterian) to rifting-related volcanism (Ngaterian and younger). Thick pillow lavas were deposited in the middle Clarence Valley but are absent in the Coverham area. Tensional basins began to appear elsewhere during the Ngaterian, e.g. Great South Basin, Westland (see Laird 1980).

Raukumara Series (*fig. 4.7*):

This was mainly a period of passive sedimentation with subduction having now ceased. Nidd Sandstone was laid down in the Coverham Block and Burnt Creek sedimentation continued in the eastern blocks. Closer to shore in the middle Clarence Valley, mid-inner slope upper Bluff Sandstone was being deposited (Reay 1980). In the Teratan, further fault movement, this time reverse, took place on the Ouse Fault juxtaposing the Split Rock with Burnt Creek rocks.

Mata Series (*fig. 4.8*):

The deposition of a widespread glauconitic sheet (Paton) over the top of all three blocks of Sawtooth and Coverham Group rocks heralded the beginning of a new sedimentary regime. Apart from minor posthumous movement on the Ouse Fault, stability is suggested with the Motuan - Ngaterian basins having become relic. Regional subsidence followed with deposition of Whangai muds and the beginning of Amuri Limestone deposition in a shelf environment.

Early Cenozoic

Limestone deposition continued on a passive, stable shelf environment.

Mid - Late Cenozoic:

After the deposition of the Amuri Limestone deformation associated with the initial stages of the Kaikoura Orogeny began during the Miocene. Movement on the Clarence and Kekerengu Faults and the erosional products of this movement have been well documented by Prebble (1976, 1980). The two faults have quite a different trend to the Cretaceous Ouse, Champagne and Pikes Faults (see Plate 1 - for trend of Kekerengu Fault). Uplift of the Seaward Kaikoura Range also occurred at this time leading to the formation of the Benmore Anticline and northward tilting of the Coverham area. No movement appears to have occurred on the Champagne, Ouse or Pikes Faults during this uplift although minor movement is probable on a small number of recent faults observed and also on a prominant conjugate fault set ubiquitous throughout the area trending c.090° and 130°. This suggests that this northern part of the Seaward Kaikoura Range at least, was uplifted essentially as one northward tilting single 'rigid' block with movement on the two major bounding faults. Originally adjoining parts of the sequence are likely to be transported to the southwest and northeast due to trans-current movement on the Clarence and Kekerengu Faults. The geological map (Plate 1) is essentially a cross-section and a plan map of the area in one. Northward plunging structure in the northern part has given us a cross-sectional picture whilst the remainder in the southern two-thirds of the map area give us a plan-view more or less unchanged since the Cretaceous (see *fig. 4.9c*).

ANALOGUE

The present day East Coast North Island subduction zone is an excellent analogue to this model. Offshore seismic work has indicated the presence of numerous sub-parallel anticlines, synclines, ridges, troughs, slope basins and faults in a zone extending from the present coastline up to c.160km offshore (Pettinga and Lewis 1985). Their figure 1, p.182, with the various formations in the study area superimposed on it appears in *figure 4.10*. Orientations of the overall strike and axial trend of the folds are obviously different than they were in the Cretaceous (estimated at northeast/southwest). A cross-section from Lewis 1980 is also valuable in this context (*figure 4.11*).

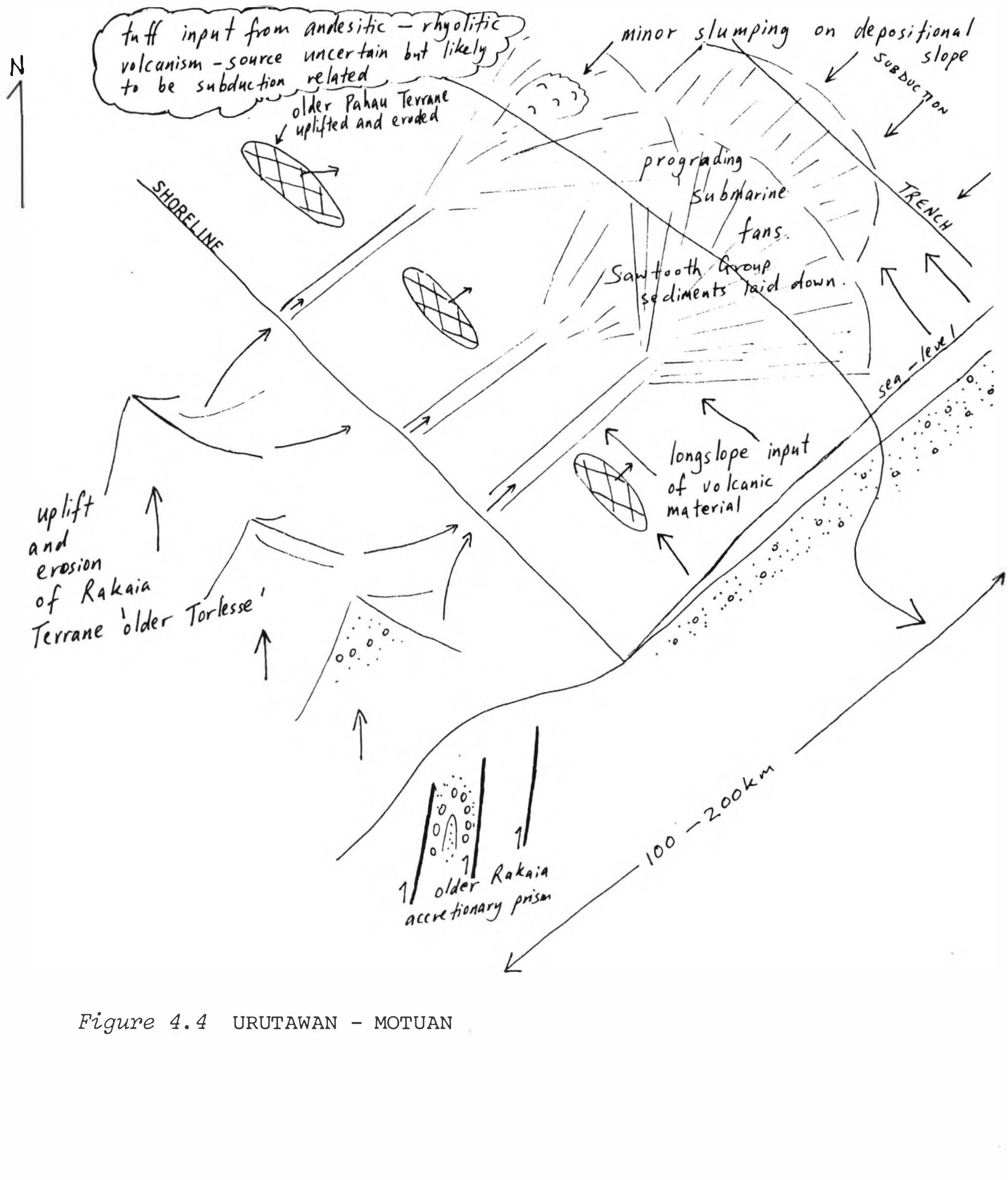


Figure 4.4 URUTAWAN - MOTUAN

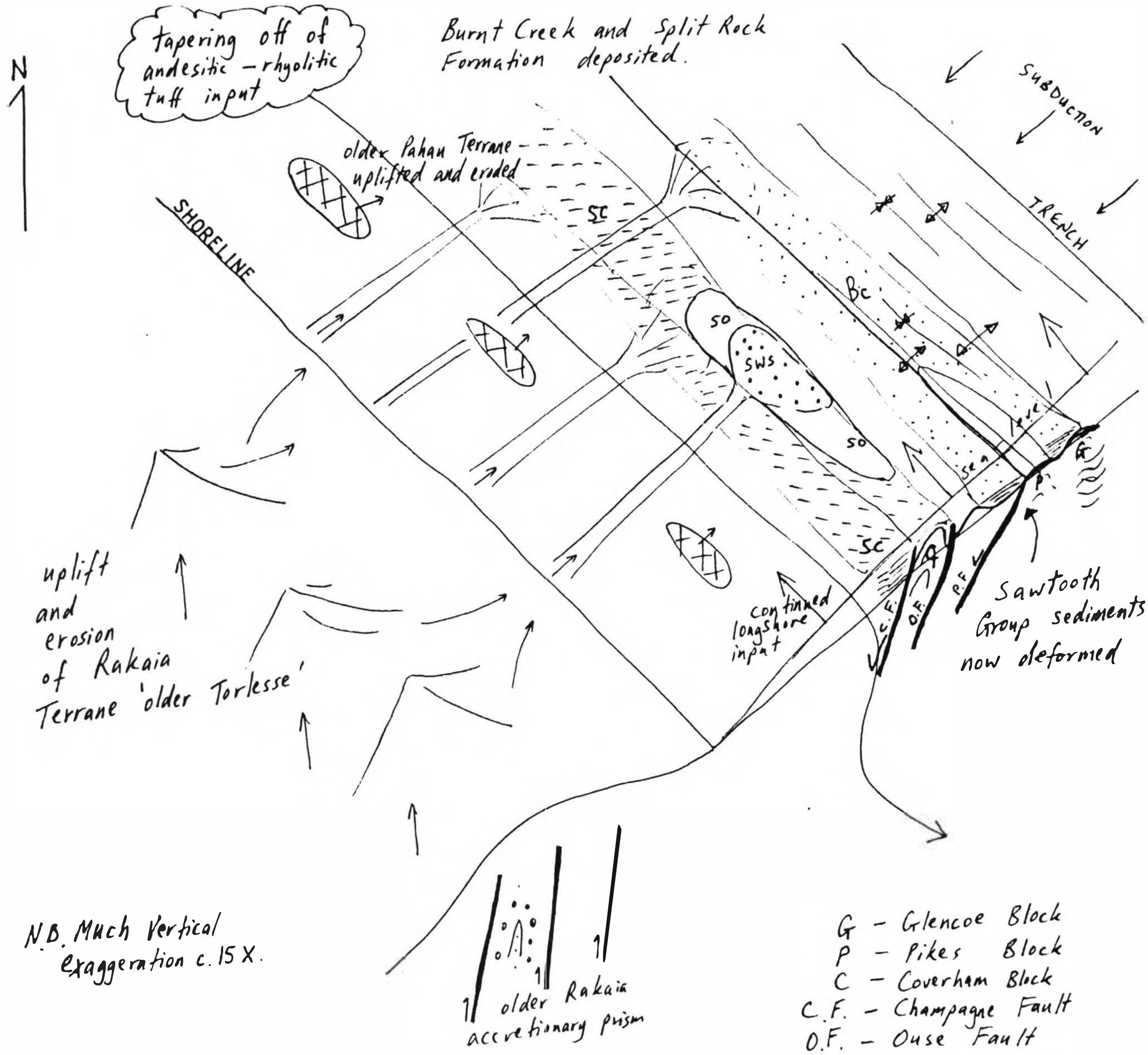


Figure 4.5 MID MOTUAN - EARLY NGATERIAN

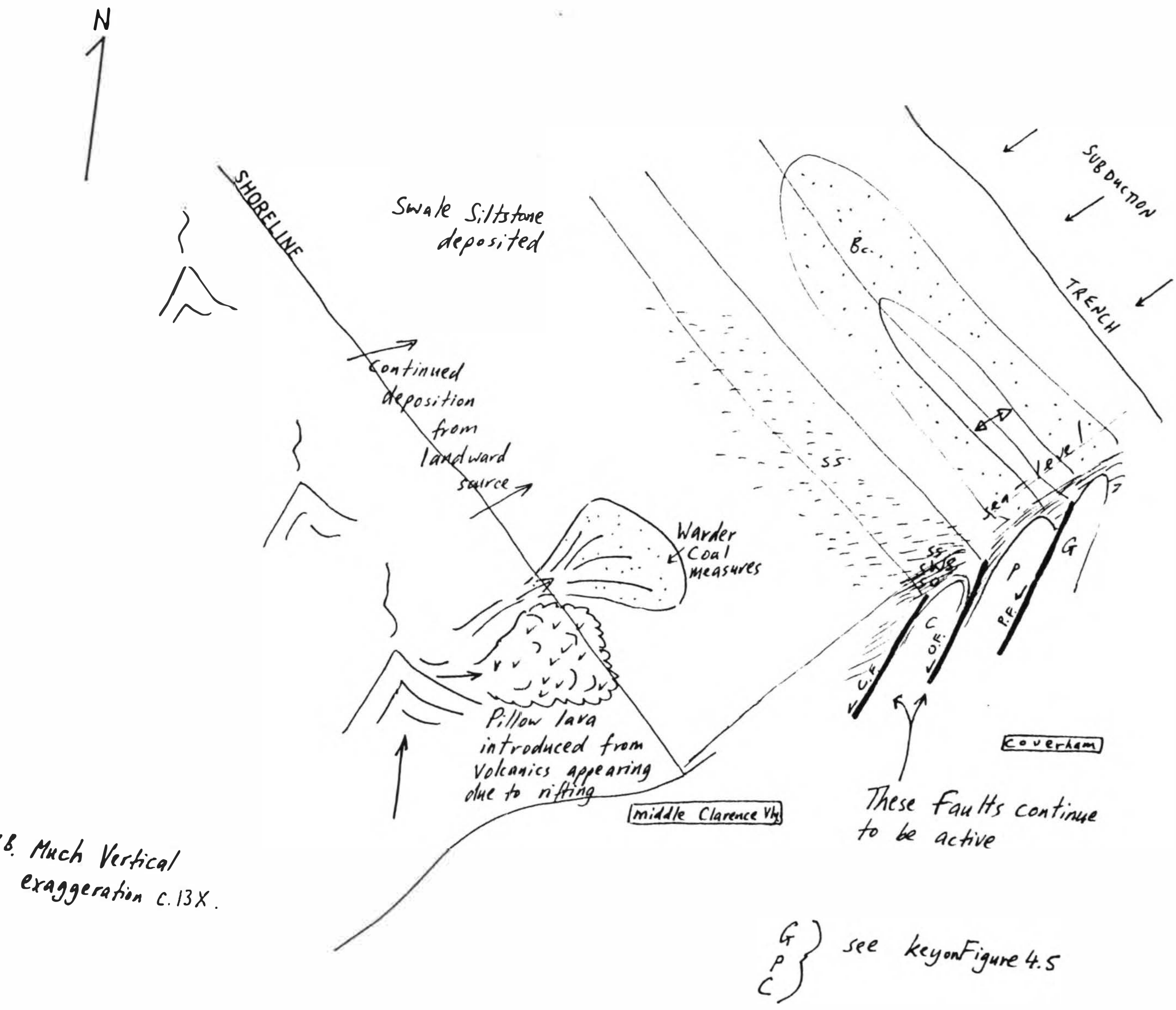


Figure 4.6 NGATERIAN

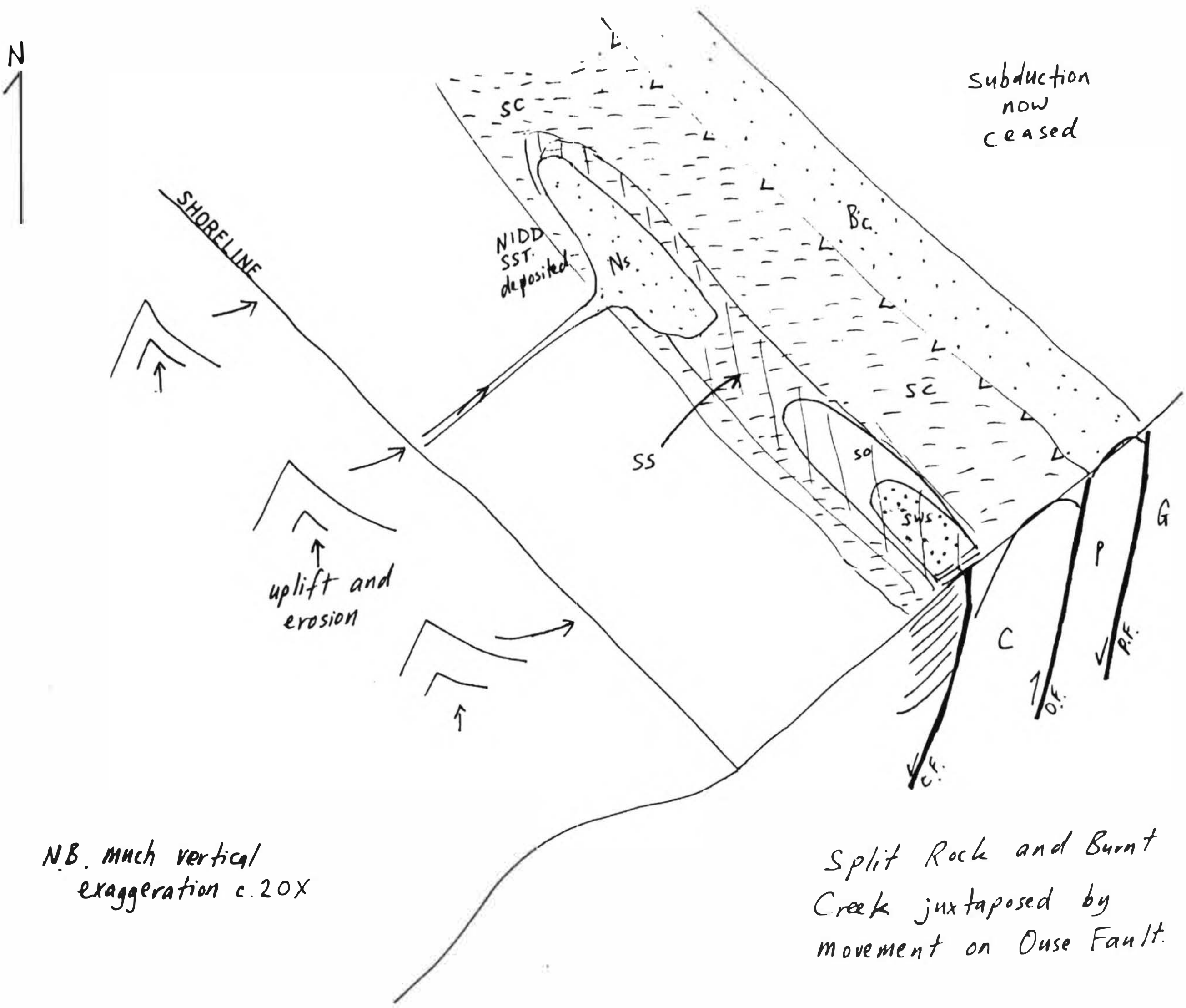
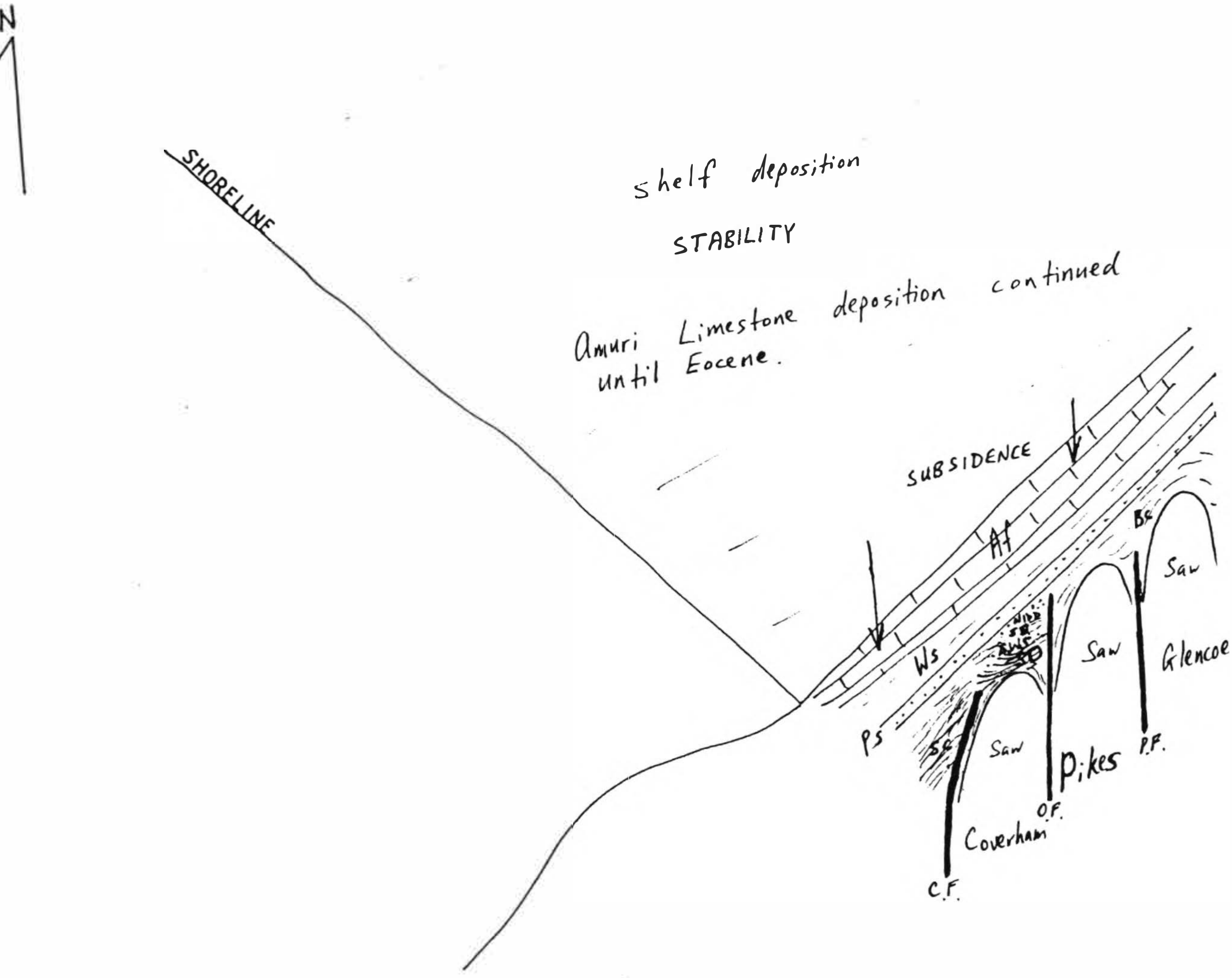


Figure 4.7 Raukumara Series



Much V.E.;c.20X

Figure 4.8 Mata Series

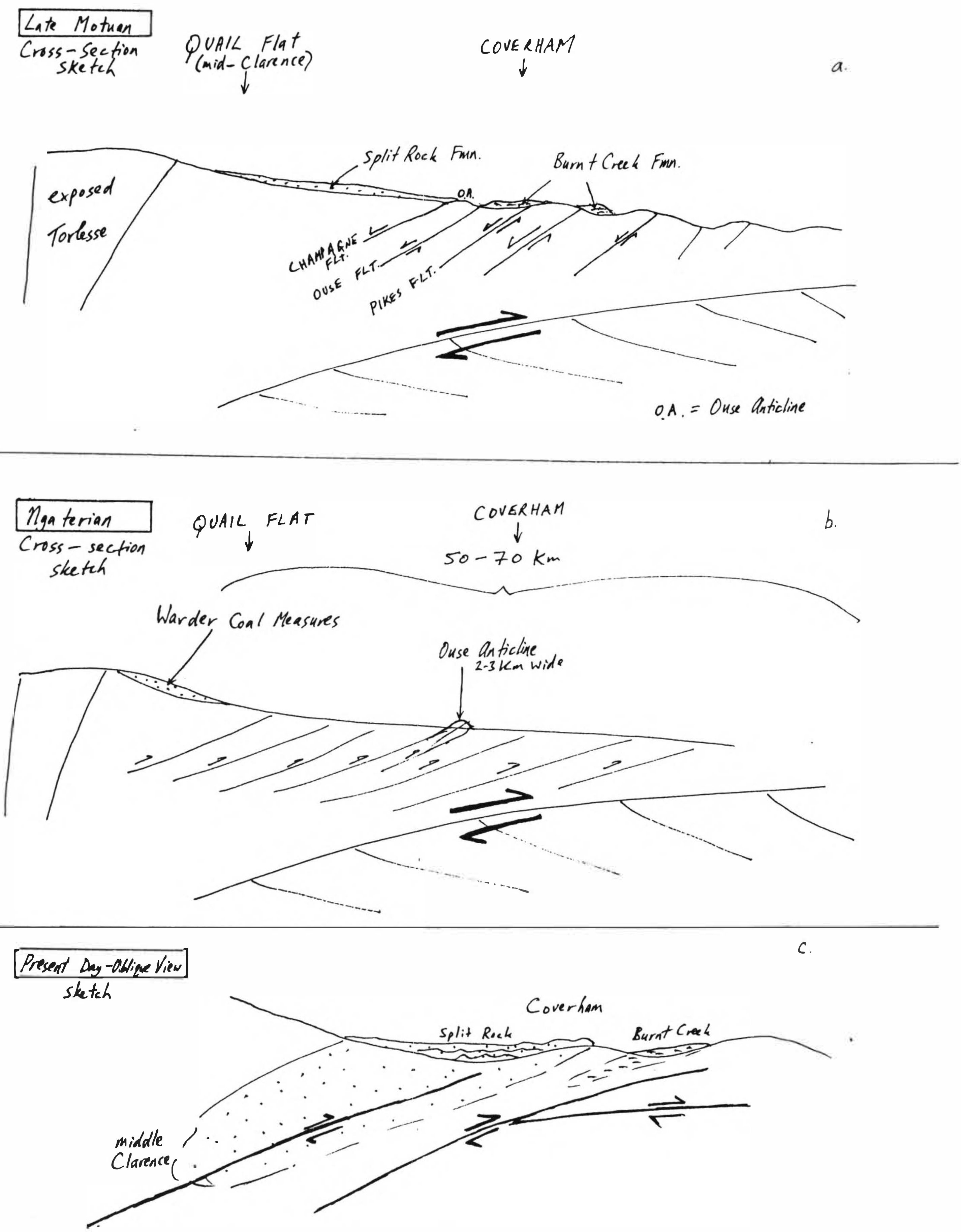


Figure 4.9 a. Sketched cross-section through Coverham-Quail Flat (middle Clarence) area in late Motuan. b. Cross-section through same area in Ngaterian. c. Oblique view down the Clarence Valley today with major transcurrent faults marked.

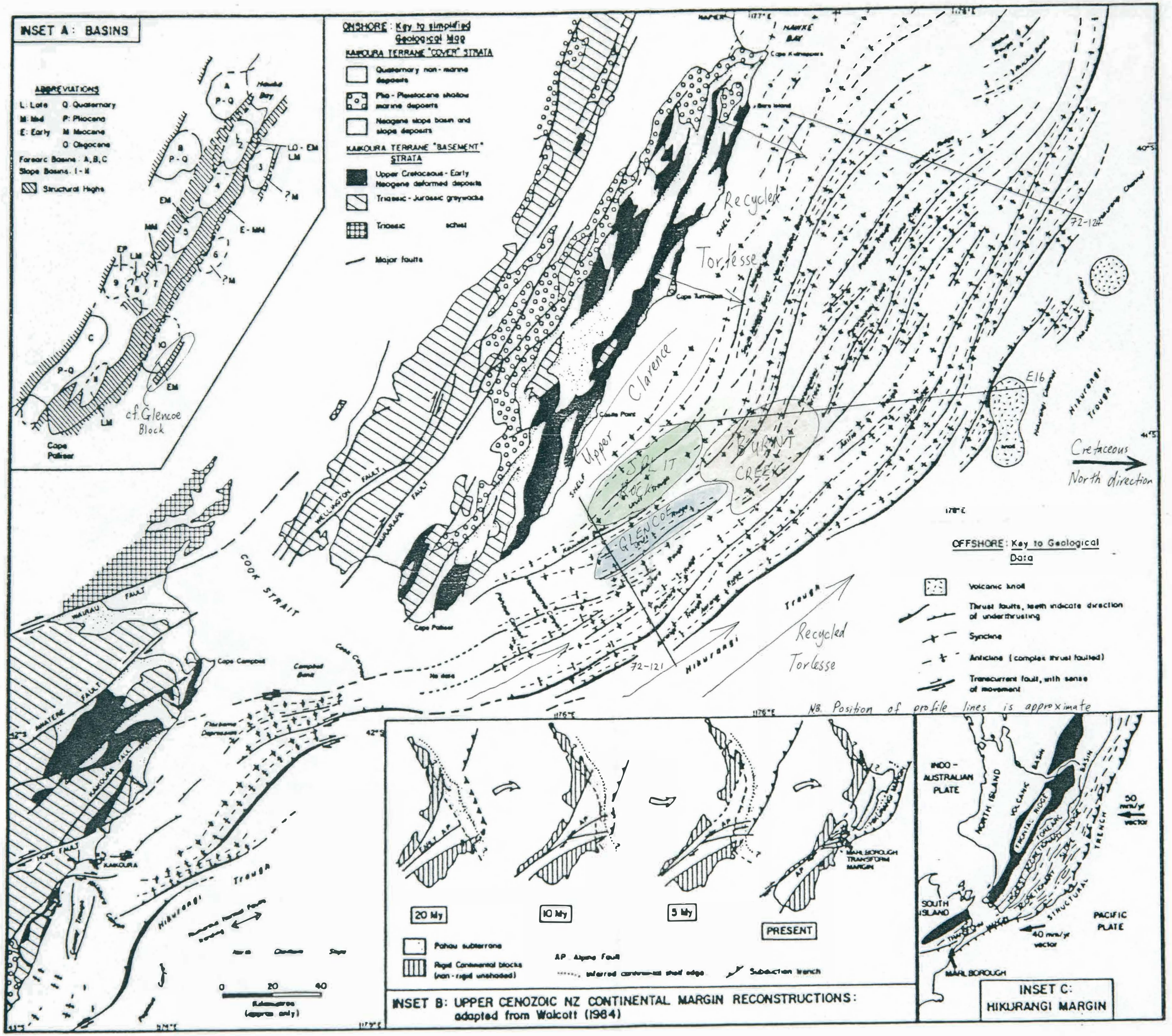


Figure 4.10 Reproduction of Figure 1 of Pettinga and Lewis (1985). Various Cretaceous formations of the study area are superimposed on this probably analogous present day accretionary prism setting of east coast North Island. The off-shore geology has been constructed from seismic profile analysis. Cross-section lines refer to *figure 4.11* of this thesis.

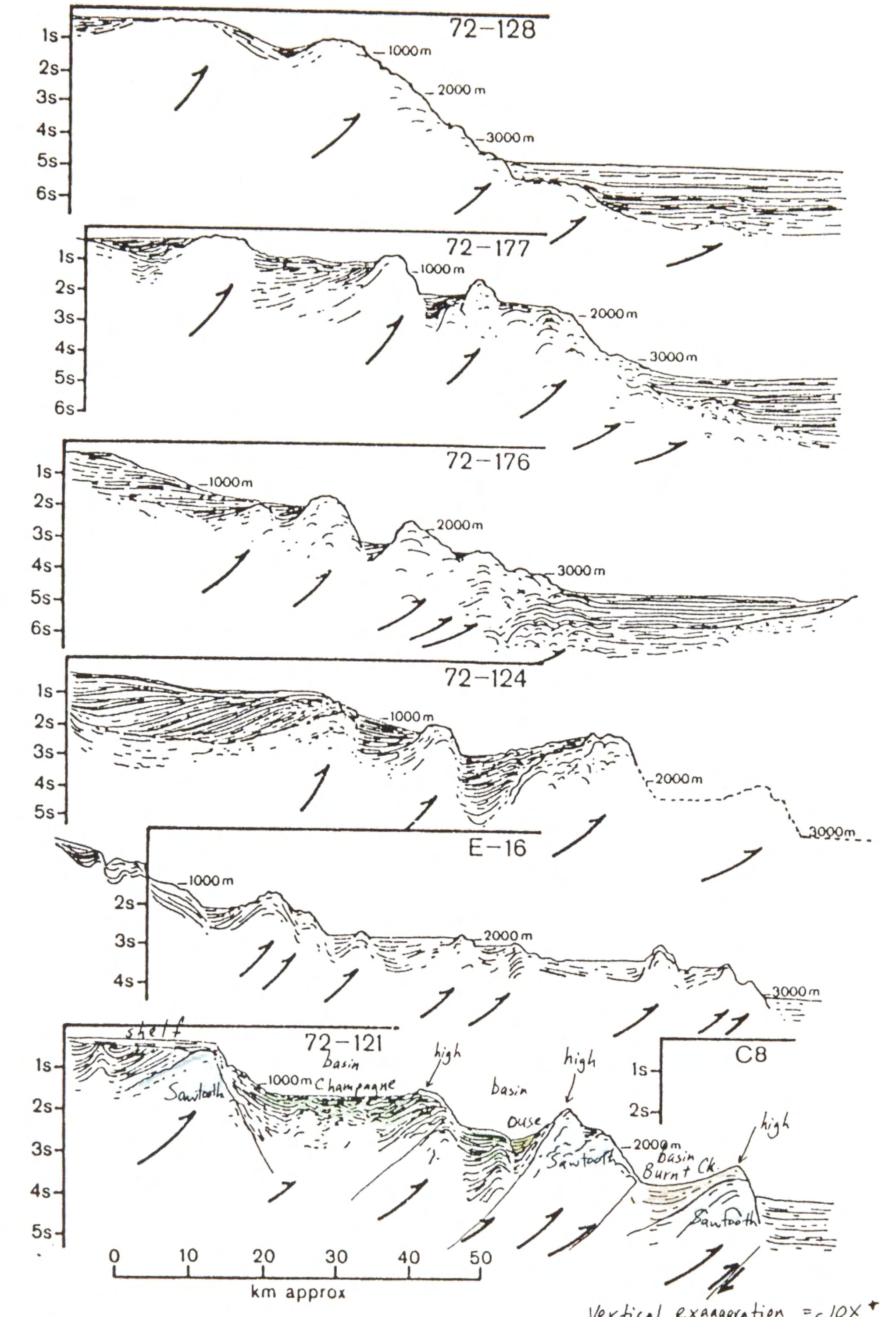


Fig. 5. Tracings of seismic profiles from the Hikurangi Oblique-subduction Margin, continental shelf (left) to Hikurangi Trough (right). Arrows represent probable position of thrust faults. At left, two-way travel time in seconds. On slope, depth to seabed in metres. Horizontal scale approximate only. A line sloping at 45° on the profiles represents a surface with a dip of about 6° in the line of the profile. Note underthrust toe of slope in 72-176 and 72-177. Basin-fill sediments mainly Quaternary in age. Ridge-crest strata range from Quaternary to Early Tertiary but are mainly Late Tertiary.

Figure 4.11 Formations in the Coverham area are superimposed on this seismic profile of the present day east coast North Island Hikurangi Oblique-subduction margin (after Lewis 1980, fig. 5). Position of seismic profiles appear on *figure 4.10*.

DISCUSSION

Model:

Two possible mechanisms by which intra-Motuan deformation occurred have been suggested (p.124) and are discussed below.

The short-lived intra-Motuan event could simply represent the influence of faulting and folding in the underlying subduction complex propagating upwards to affect the Sawtooth rocks. However evidence of major bedding parallel extension, high strength contrasts between sandstones and mudstones and flow of mudstones suggests superficial deformation suggesting that an alternative 'slide model' should be considered. The slide model accomodates for the presence of coeval tensional and compressional features which mapping has uncovered in the Coverham and Awatere areas. Large scale submarine slides straddling present day subduction zones have been reported e.g. Moore et. al. (1976) report on the Bassein Slide in the northwest Sundra Arc - near Burma. The total area covered by the slide is 4000km² and the total volume of the slide deposits = c.900km³. Mean thickness of the deformed beds may have been 2-4km. The slide which was initiated on a slope of only 1°, comprises blocks up to 360m and 2.8km between faults, blanketed by younger slope sediments. This slide is much more extensive and thicker than proven Sawtooth. Superficial sliding on very low angled slopes (1-2°) has been reported in the east coast North Island accretionary prism-subduction zone setting; e.g. Kidnappers Slump, Paoanui Slump (Lewis 1971). These slides appear to have produced both tensional normal faulting at the head-wall scarp and very low angle thrusting in the compressional toe zone (Lewis 1971, fig. 3, p.102).

Other means by which the Sawtooth sediments were deformed by a short-lived event are possible however there is a constraint on any model developed in that this study only maps a small portion, probably only a few percent of the width of the accretionary complex. Further detailed mapping may uncover unequivocal slide deposits or if not the 'accretion propogation' model (p.124) for a short-lived event may be favoured.

General:

One strong impression of these rocks gained during the course of this study is that there are stronger similarities between Coverham Group and Sawtooth Group rocks and between Split Rock and Burnt Creek rocks than there seemed to be at the outset. For instance, Champagne Member is very similar to parts of Sawtooth Group in the Coverham Block and beds of the upper part of the Ouse Member are very similar to parts of the Burnt Creek Formation. This is significant in the context of environmental analysis and suggests that these sediments were deposited in a similar depositional environment. In many other accretionary prisms a more marked difference between the sediments occurs e.g. Nias Island, Indonesia (Moore and Karig 1980) where the accretionary complex contains pillow lavas, cherts, and pelagic limestones of oceanic affinity while the slope basin deposits are barren of these components. East coast North Island also has pillow lavas, cherts and pelagic limestones (Pettinga 1982) as does the Esk Head mélange and western part of the Pahau Terrane (J.D. Bradshaw - pers. comm.).

It seems likely that the Sawtooth represents either 'younger Pahau' in which exotic components have yet to reach the surface or an earlier slope basin partly involved in accretion. Even though further unconformities may be found within Sawtooth to the south, the Sawtooth can still be Torlesse. Rocks I have observed in the Blind Saddle region 60km to the south of the study area are almost identical to those of Sawtooth in the study area. Relationships between the study area and the vast tracts of Torlesse to the southwest will not become apparent until more detailed work has been done and the concept of Torlesse Supergroup will consequently remain vague until more studies are completed.

Future Work:

Any future work will probably have the ultimate aim of testing further the two or three possible models for these rocks.

A geochemical project sampling the Sawtooth/non Sawtooth boundary to attempt to identify whether a geochemical change occurs across it has already begun.

With respect to mapping, it is obviously worthwhile primarily to map the area between Mead Stream and Whiskey Stream which is the northeastern boundary of Reay's map (Reay - in prep.).

Tracing the Pikes and Ouse Faults and Burnt Creek Formation to the south into the Seaward Kaikoura Range would obviously be another priority. The primary objective of this work would be to look for an additional angular unconformity or unconformities and to discover how the formations of the study area link to the Torlesse Supergroup of the Seaward Kaikoura Range.

Finer biostratigraphic age division of the thick (2km+) Urutawan - Motuan sequence would aid interpretation of the area. This would be particularly useful for dating on opposite sides of the major faults and between different formations of the Coverham Group rocks. Also it may help to show up relationships between the blocks of Sawtooth Group. While macrofauna are uncommon in the Sawtooth they do occur and can be quite well preserved in the less deformed parts e.g. Kekerengu River. Palynological studies in the Sawtooth have so far proved to be of limited value. Perhaps radiolaria will be found in the mudstones in the future enabling better dating.

Geochemical analysis and dating of igneous conglomerate clasts would aid tracing of the igneous source(s) for these clasts in the Sawtooth and Coverham Group conglomerates.

CHAPTER V

CONCLUSIONS

1. The contact between Sawtooth Group (Torlesse-like) and Coverham Group (non-Torlesse) is unconformable everywhere in the study area. The unconformity is most commonly angular but in places a paraconformity is present. A further unconformity occurs at the base of Ouse Member indicated by a local discordance, conglomerate and a change in type of sedimentation. It is thought to reflect the presence of a growing fold (Ouse Anticline).

2. The Split Rock Formation, previously used only in the middle Clarence Valley, can be extended to the Coverham area with four new members being recognised - Champagne, Ouse, Wharfe, Swale. The Torlesse/non-Torlesse boundary occurs at the base of the oldest of these units, the Champagne Member, not as traditionally thought at the base of the Ouse Member. In Ouse Stream the base of the formation is 2km further downstream from the base of the Ouse Member at the entrance to the Ouse gorge.

3. The pattern of deposition and deformation suggests an accretionary prism setting for these rocks. Sawtooth Group rocks are likely to represent 'younger' Pahau Terrane rocks (Bishop et. al. 1985) which were recycled from 'older' Pahau and Rakaia Terrane rocks further up the slope. They were probably deposited in a submarine fan depositional environment which lay above a subduction complex of 'older' Pahau Terrane, and were subsequently deformed by a single intra-Motuan event either tectonic or perhaps a huge submarine slide, creating widespread unconformity between them and the Coverham Group slope basin deposits. Continuing instability is likely to have led to growing folds and further minor unconformities.

4. The partly coeval Split Rock and Burnt Creek Formations were probably deposited some distance apart in different basins

separated by structural high(s) and were juxtaposed by low angle reverse movement in the Late Cretaceous.

5. The termination of the Rangitata Orogeny occurred in a progressive and evolutionary way representing a mid-Late Cretaceous i.e. Motuan - Ngaterian change from a compressional subduction regime to a tensional rifting regime. This change is indicated by the gradual disappearance of subduction-related acid igneous tuffs and their replacement by post tectonic Tapaenuku Igneous Complex, Lookout Volcanics, and origin of new sedimentary basins. However locally, faults within the old subduction complex may have continued to adjust as late as the Teratan stage e.g. Pikes Fault.

6. Structural/deformation characteristics cannot be used as a criteria for separating the Torlesse rocks from non-Torlesse rocks in the study area. At a distance of c.200m from tectonised contacts of the two Groups one can distinguish unequivocal Sawtooth and non-Sawtooth rocks, however closer to tectonic contacts the two sets of rocks have very similar deformation styles and this coupled with very similar lithologies makes it impossible to separate the two units in many places. Only careful mapping which identifies changes in structural style along strike allows real comparison of the units.

7. It is dangerous to assume that 'Torlesseness' is a certain and particular state of deformation. The Torlesse in the study area exhibits a whole spectrum of deformation from highly deformed 'broken formation' to more or less undisturbed beds with fine examples of sole structures etc.

8. More detailed biostratigraphic age subdivision of the Motuan during which c.2km thick deposits were laid down, would aid further interpretation of the Torlesse/non-Torlesse rocks and the conclusion of the 'Rangitata' orogenic episode.

9. This study has not differentiated the Sawtooth Group into formations or facies. Further work may enable either division of the group into formations or the recognition of a number of facies within it.

10. Andesitic-rhyolitic volcanism which from trace element analysis of tuffs is likely to be subduction-related, was common in the late Early Cretaceous (pre-Urutawan/Motuan).

ACKNOWLEDGMENTS

Firstly I would like to thank Dr J.D. Bradshaw for initiating this mapping project and following it through with patient and interested supervision. Dr S.W. Weaver is due thanks for help with geochemical analysis of the tuffs.

I am grateful to the D.S.I.R. for funding and paleontological servicing. In particular, thank you to Dr I.G. Speden, Dr J.I. Raine and G.J. Wilson. Discussion with Dr M.G. Laird and Dr M.B. Reay has proved most valuable.

Further thanks are due to all members of the technical and academic staff of the Geology Department for their support.

Finally, I would like to thank Judith Terpstra, John Armitage, Gilda Otway and Mark Lawrence for help in the field, the Murray's and Deans of Glencoe and Coverham areas for access to their land and use of their shearing quarters, and to Ms Sherelle Dennis for typing the manuscript.

REFERENCES

Abbate, E.; Bortolotti, V.; Passerini, P. 1970: Development of the Northern Appennines Geosyncline - Olistostromes and Ostoliths. *Sedimentary geology* 4:521-557.

Adams, C.J.; Gabites, J.E. 1985: Age of metamorphism and uplift in the Haast Schist Group at Haast Pass, Lake Wanaka and Lake Hawea, South Island, New Zealand. *New Zealand journal of geology and geophysics* 28:85-96.

Adams, C.J.D.; Nathan, S. 1979: Cretaceous chronology of the Buller Valley, South Island, New Zealand. *New Zealand journal of geology and geophysics* 21:455-462.

Adams, C.J.D.; Oliver P.J. 1979: Potassium-argon dating of Mt. Somers Volcanics, South Island, New Zealand. Limitations in dating Mesozoic volcanic rocks. *New Zealand journal of geology and geophysics* 22:455-463.

Adams, C.J.D. Bishop, D.G.; Gabites, J.E. (in press): Potassium-argon age studies of a low-grade, progressively metamorphosed greywacke sequence, Dansey Pass, South Island, New Zealand. *Journal of the Geological Society of London.*

Andrews, P.B.; Speden, I.G.; Bradshaw, J.D. 1976: Lithological and paleontological content of the Carboniferous - Jurassic Canterbury Suite, South Island. *New Zealand journal of geology and geophysics* 19:791-819.

Barley, M.E. (in press): Origin and evolution of mid Cretaceous garnet-bearing intermediate and silicic volcanics from Canterbury, New Zealand. *Journal of volcanological and geothermal research.*

Bishop, D.G.; Bradshaw, J.D.; Landis, C.A. 1985: Provisional terrane map of South Island, New Zealand. *In*: Howell, D.G. *(ed.)*. Tectonostratigraphic terranes of the Circum-Pacific Region: Pacific Southwest Quadrant. p.515-522.

Blake, M.C.; Jones, D.L.; Landis, C.A. 1974: Active continental margins: contrasts between California and New Zealand. *In*: Burk, C.A. and Drake, C.L. *(eds.)*. The geology of continental margins. New York, Springer. p.853-872.

Bouma, A.H. 1962: Sedimentology of some flysch deposits. Amsterdam, Elsevier. 168p.

Bradshaw, J.D.; Andrews, P.B. 1980: Torlesse Terrane excursion. Geological Society of New Zealand. Christchurch conference field guide:C1-C12.

Bradshaw, J.D. Laird, M.G.; 1980 : Triassic-Jurassic rocks and Cretaceous "break-up" sequences in the northern South Island. Wellington, Geology Dept, Victoria University of Wellingon. 53p.

Bradshaw, J.D.; Adams, C.J.; Andrews, P.B. 1981: Carboniferous to Cretaceous on the Pacific margin of Gondwana: The Rangitata Phase of New Zealand. *In*: Cresswell, M.M. and Vella, P. *(eds.)*. Gondwana five: selected papers and abstracts of papers presented at the Fifth International Gondwana Symposium. Rotterdam, Balkema. p.217-221.

Bradshaw, J.D.; Andrews, P.B.; Field, B.D. 1983: Swanson Formation and related rocks of Marie Byrd Land and a comparison with the Robertson Bay Group of Northern Victoria Land. *In*: Oliver, R.L.; James, P.R. and Jago, J.B. *(eds.)*. Antarctic earth science: proceedings of the Fourth International Symposium on Antarctic Earth Sciences ... Canberra, Australian Academy of Science. p.274-279.

Bray, C.J.; Karig, D.E. 1985: Porosity of sediments in accretionary prisms and some implications for dewatering processes. *Journal of geophysical research* 90:768-778.

Campbell, J.D.; Warren, G. 1965: Fossil localities of the Torlesse Group in the South Island. *Transactions of the Royal Society of New Zealand* 3(8):99-137.

Carson, B.; von Huene, R.; Authur, M.A. 1982: Small-scale deformation and physical properties related to convergence in Japan Trench slope sediments. *Tectonics* 1:277-302.

Challis, G.A. 1966: Cretaceous stratigraphy and structure of the Lookout area, Awatere Valley. *Transactions of the Royal Society of New Zealand* 4:119-137.

Coombs, D.S.; Landis, C.A.; Norris, R.J.; Sinton, J.M. Borns, D.J.; Craw, D. 1976: The Dun Mountain ophiolite belt, New Zealand, its tectonic setting, constitution and origin, with special reference to the southern portion. *American journal of science* 276:561-603.

Cowan, D.S. 1985: Structural styles in Mesozoic and Cenozoic mélanges in the western Cordillera of North America. *Geological Society of America bulletin* 96:451-462.

Elter, P.; Raggi, G. 1965: Contributo alla conoscenza dell' Appennino ligure: 1. Osservaziono preliminari sulla posizione delle ofioliti nella zona di Zignago (La Spezia); 2. Considerazione sul problema degli olistostromi. *Bolletino Societa Geologica Italiana* 84(3):303-322.

Folk, R.L.; Andrews, P.B.; Lewis, D.W. 1970: Detrital sedimentary rock classification and nomenclature for use in New Zealand. *New Zealand journal of geology and geophysics* 13:937-968.

Gair, H.S. 1967: The question of post-Rangitata peneplanation in New Zealand. (An investigation of Cretaceous peneplanation in relation to unconformities in Upper Jurassic and Cretaceous sequences). Unpublished Ph.D. thesis, University of Canterbury Library.

Hall, W.D.M. 1963: The Clarence Series at Coverham, Clarence Valley. *New Zealand journal of geology and geophysics* 6(1):28-37.

——— 1965: The geology of Coverham and the upper Waima Valley, Marlborough. Unpublished M.Sc. thesis, Victoria University of Wellington Library.

Hector, J. 1886: Reports on geological explorations. *Colonial Museum and Geological Society of New Zealand reports* 17.

Hsü, K.J. 1968: Principles of mélanges and their bearing on the Franciscan-Knoxville paradox. *Geological Society of America bulletin* 79:1063-1074.

Johnston, M.R. 1980: Geology of the Tinui-Awatoitoi district. *New Zealand Geological Survey bulletin* 94. 64p.

Johnston, M.R.; Browne, P.R.L. 1973: Upper Jurassic and Cretaceous conglomerates in the Tinui-Awatoitoi district, eastern Wairarapa (note). *New Zealand journal of geology and geophysics* 16:1055-1060.

King, L.C. 1937a: The Tertiary sequence in north-eastern Marlborough, New Zealand. *Transactions of the Royal Society of New Zealand* 67:21-32.

——— 1937b: The structure of north-eastern Marlborough, New Zealand. *Transactions of the Royal Society of New Zealand* 67:33-46.

Laird, M.G. 1980 : The late Mesozoic fragmentation of the New Zealand segment of Gondwana. *In*: Cresswell, M.M. and Vella, P. *(eds.)*. Gondwana five: selected papers and abstracts of papers presented at the Fifth International Gondwana Symposium. Rotterdam, Balkema. p.311-318.

Laird, M.G.; Lewis, D.W. 1980: Marlborough Excursion. Geological Society of New Zealand. Christchurch conference field guide:B1-B17.

——— 1986: Growth-fault control of mid-Cretaceous shallow marine storm-influenced mass flow sedimentation, northeast South Island, New Zealand. (Abstract). Twelfth International Sedimentological Congress, Canberra, Australia.

Lash, G.G. 1985: Accretion related deformation of an ancient (early Paleozoic) trench-fill deposit, central Appalachian orogen. *Geological Society of America bulletin* 96:1167-1178.

Le Mesurier, W.E.; Wade, F.A. 1976: Volcanic history in Marie Byrd Land. *In*: Gonzalez-Ferran, O. *(ed.)*. Andean and Antarctic volcanic problems. Rome, International Association of volcanology and chemistry. Earth's interior. p.398-422.

Lensen, G.J. 1962: Sheet 16 - Kaikoura (1st edition). Geological map of New Zealand 1:250,000. Wellington. DSIR.

Lewis, D.W. 1982: Practical sedimentology. Apteryx.

Lewis, K.B. 1971: Slumping on a continental slope inclined at 1°-4°. *Sedimentology* 16:97-110.

——— 1980: Quaternary sedimentation in the Hikurangi oblique subduction and transform margin, New Zealand. *In*: Ballance, P.F.; Reading, H.G. *(eds.)*. Sedimentation in oblique-slip mobile zones. International Association of Sedimentologists. (Special Pub. 4). p.171-189.

——— (ed)(in press): New seismic profiles, cores and dated rocks from the Hikurangi Margin. *NZOI oceanographic field report.*

MacKinnon, T.C. 1980: Sedimentologic, petrographic and tectonic aspects of Torlesse and related rocks: South Island, New Zealand. Ph.D. thesis, University of Otago Library.

——— 1983: Origin of Torlesse terrane and coeval rocks, South Island, New Zealand. *Geological Society of America bulletin* 94:967-985.

McKay, A. 1886: On the geology of the eastern part of the Marlborough provincial district. *New Zealand Geological Survey reports on geological exploration during 1885* 17:27-136.

——— 1890: On the geology of Marlborough and the Amuri district of Nelson. *New Zealand Geological Survey reports on geological exploration during 1885* 20:85-185.

——— 1892: On the geology of Marlborough and south-east Nelson, part II. *New Zealand Geological Survey reports on geological exploration during 1885* 21:1-30.

MacPherson, E.O. 1948: The upper Senonian transgression in New Zealand. *New Zealand journal of science and technology sect. B.* 29(6):280-296.

——— 1952: The stratigraphy and bentonitic shale deposits of Kekerengu and Blue Slip, Marlborough. *New Zealand journal of science and technology sect. B.* 33(4):258-286.

Montague, T.G. 1981: Cretaceous stratigraphy of the Mt. Lookout area and its relation to the proposed regional unconformity at the end of the Rangitata Orogeny. Unpublished M.Sc. thesis, University of Canterbury Library.

Moore, D.G.; Curray, J.R.; Emmel, F.J. 1976: Large submarine slide (olistostrome) associated with Sundra Arc subduction zone, northeast Indian Ocean. *Marine geology* 21:211-226.

Moore, G.F.; Karig, D.E. 1980: Structural geology of Nias Island, Indonesia: implications for subduction zone tectonics. *American journal of science* 280:193-223.

Moore, J.C.; Karig, D.E. 1976: Sedimentology, structural geology, and tectonics of the Shikoku subduction zone, southwestern Japan. *Geological Society of America bulletin* 87:1259-1268.

Moore, P.R. 1978: Petrography of Late Jurassic - Late Cretaceous rocks from Koranga Valley, Ruakumara Peninsula. *New Zealand journal of geology and geophysics* 21:189-197.

Moore, P.R.; Speden, I.G. 1979: Stratigraphy, structure and inferred environments of deposition of the early Cretaceous sequence, eastern Wairarapa, New Zealand. *New Zealand journal of geology and geophysics* 22:417-434.

——— 1984: The Early Cretaceous (Albian) sequence of eastern Wairarapa, New Zealand. *New Zealand Geological Survey bulletin* 97:98p.

Nicol, E.R. 1977: Igneous petrology of the Clarence and Awatere Valleys, Marlborough. Ph.D. thesis. Victoria University of Wellington Library.

Oliver, P.J.; Mumme, T.C.; Grindley, G.W.; Vella, P. 1979: Paleomagnetism of the Upper Cretaceous Mt. Somers volcanics, Canterbury, New Zealand. *New Zealand journal of geology and geophysics* 22:199-212.

Osborne, M.T. 1981: The stratigraphy and structure of the Clarence-Kekerengu sector, Marlborough. Unpublished M.Sc. thesis, housed at University of Canterbury. 141p.

Pearce, J.A.; Harris, N.B.W.; Tindle, A.G. 1984: Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. *Journal of petrology* 25:956-983.

Pettinga, J.R. 1982: Upper Cenozoic structural history, coastal southern Hawkes Bay, New Zealand. *New Zealand journal of geology and geophysics* 25:149-191.

Pettinga, J.R.; Lewis K.B. 1985: Anatomy of the Kaikoura Terrane in the obliquely convergent Australia - Pacific plate boundary, North Island, New Zealand. (Abstract). Third Circum Pacific Terrane Conference, Sydney. Geological Society of Australia abstracts no. 14.

Prebble, W.M. 1976: The geology of the Kekerengu-Waima River District, Northeast Marlborough. Unpublished M.Sc. thesis, Victoria University of Wellington Library.

——— 1980: Late Cainozoic sedimentation and tectonics of the East Coast Deformed Belt, in Marlborough, New Zealand. *In*: Ballance, P.F.; Reading, H.G. *(eds.)*. Sedimentation in oblique-slip mobile zones. International Association of Sedimentologists. (Special Pub. 4). p.217-228.

Raine, J.I.; Speden, I.G.; Strong, C.P. 1981: New Zealand. *In*: Reyment, R.A.; Bengtson, P. *(eds.)*. Aspects of Mid-Cretaceous Regional Geology. Academic Press, London. p.221-267.

Ramsay, J.G. 1967: Folding and fracturing of rocks. New York, McGraw-Hill.

Reay, M.B. 1980: Cretaceous and Tertiary stratigraphy of part of the middle Clarence Valley, Marlborough. Unpublished M.Sc. thesis, University of Canterbury Library.

Ritchie, D.D.; Bradshaw, J.D. 1985: Clarence-Kekerengu field trip, Marlborough 1985. Geological Society of New Zealand. Christchurch conference field guide.

Roddick, J.A. 1983: Circum-Pacific plutonic terranes: an overview. *In*: Roddick, J.A. *(ed.)*. Circum-Pacific Plutonic Terranes. Geological Society of America memoir 159:1-4.

Smale, D. 1978: The composition of a Torlesse conglomerate - Ethelton, North Canterbury. *New Zealand journal of geology and geophysics* 21:699-711.

Speden, I.G. 1977: Taitai Series (Early Cretaceous) and the elimination of the Mokoiwian Stage. *New Zealand journal of geology and geophysics* 20:537-562.

Sporli, K.B. 1980: New Zealand and oblique-slip margins: tectonic development up to and during the Cainozoic. *In*: Ballance, P.F.; Reading, H.G. *(eds.)*. Sedimentation in oblique-slip mobile zones. International Association of Sedimentologists. (Special Pub. 4). p.147-170.

Stevens, G.R.; Speden, I.G. 1978: New Zealand. *In*: Moullade, M.; Nairn, A.E.M. *(eds.)*. The Mesozoic - the Phanerozoic geology of the World II. Chapter 8, New Zealand. Amsterdam, Elsevier.

Suggate, R.P. 1958: The geology of the Clarence Valley from Gore Stream to Bluff Hill. *Transactions of the Royal Society of New Zealand* 85:397-408.

Suggate, R.P.; Stevens, G.R.; Te Punga, M.T. (eds.). 1978. The geology of New Zealand. New Zealand Government Printer, 2 vols. 820p.

Surlyk, F. 1975: Fault controlled marine fan-delta sedimentation at the Jurassic-Cretaceous boundary, East Greenland. IX International Congress of Sedimentology. Abstracts. Nice, 1975. p.305-311.

——— 1978: Submarine fan sedimentation along fault scarps on tilted fault blocks (Jurassic-Cretaceous boundary, East Greenland). *Grönlands Geologiske Undersögelse bulletin* 128.

Thomson, J.A. 1919: The geology of the middle Clarence and Ure Valleys, east Marlborough, New Zealand. *Transactions of the New Zealand Institute* 51:289-349.

Tulloch, A.J. 1983: Granitoid rocks of New Zealand - a brief review. *In*: Roddick, J.A. *(ed.)*. Circum-Pacific Terranes. Geological Society of America memoir 159:5-20.

Underwood, M.B.; Bachman, S.B. 1982: Sedimentary facies associations within subduction complexes. *In*: Legget, J.K. *(ed.)*. Trench-forearc geology: sedimentation and tectonics on modern and ancient active plate margins. p.537-550.

van der Lingen, G.J.; Pettinga, J.R. 1980: The Makara Basin: a Miocene slope-basin along the New Zealand sector of the Australian-Pacific obliquely convergent plate boundary. *Special publication of International Association of Sedimentologists* 4:191-215.

Walcott, R.I. 1984: Reconstructions of the New Zealand region for the Neogene. *Palaeogeography, Palaeoclimatology, Palaeoecology* 46:217-231.

Walker, R.G. (ed.). 1983: Facies models. Geoscience Canada, reprint series 1. 317p.

Wellman, H.W. 1955: A revision of the type Clarentian section at Coverham, Clarence Valley. *Transactions of the Royal Society of New Zealand* 83:93-118.

——— 1959: Divisions of the New Zealand Cretaceous. *Transactions of the Royal Society of New Zealand* 87:99-163.

APPENDICES

APPENDIX I : Hand-specimen and Thin-section Descriptions

Appendix I(a) lists and describes rock samples collected and thin-sections made during this study. Appendix I(b) comprises tabulated point count data which is plotted on a QFR diagram on page 17. All grid references are from NZMS260 Sheet P30. Staining of plagioclase and potassium feldspar was undertaken using the methods described in Lewis (1982) p. D47. All samples and thin-sections are housed at the Geology Department, University of Canterbury.

Appendix I(a)

C.U. Rock Catalogue No.	Project Field No.	Grid Reference	Rock Type	Hand-Specimen Description	Thin-Section Description
Sawtooth Group:					
10573	Saw 14	P30/833162	tuff	white, mod.soft, tuff	tuffaceous texture
10574	Saw 17	/824157	sandstone	light grey, mod.hard, mod. well sorted, massive, medium sandstone: lithic feldsarenite	Qz, plag, sed. and volc. lithic fragments, biotite
10580	Saw 58	/803143	tuff	light coloured, mod.soft, tuff	tuffaceous texture
10582	Saw 92	/805150	tuff	white, mod.soft, mod. well sorted, calcite veined, tuff	Orthoclase phenocrysts dominant, fine qz. groundmass. calcite veins
10583	Saw 121	/771131	tuff	white, mod.soft, veined tuff	tuffaceous texture
10584	Saw 121A	/771131	tuff	white, mod.soft, tuff	tuffaceous texture
10585	Saw 140	/774118	sandstone	light brown, mod.hard, poorly sorted, medium sandstone: lithic feldsarenite	Qz, plag, biotite, muscovite, opaques, chlorite, rock fragments, calcite cemented
10586	Saw 155	/859135	tuff	red, mod.soft, mod. well sorted, veined, tuff	tuffaceous texture
10589	Saw 178	/766123	tuff	white, mod.soft, tuff	tuffaceous texture
10590	Saw 185	/879167	tuff	red, very soft, weathered, vesicular tuff	Qz, k-spar phenocrysts in glassy matrix with tuffaceous texture
10591	Saw 198	/783123	tuff	white, mod.soft, tuff	Orthoclase phenocrysts dominant, fine qz, groundmass. calcite veins, tuffaceous texture
10592	Saw 128A	/893150	acid igneous (clast)	grey, hard, poorly sorted, dacite	plag, biotite phenocrysts
10601	Saw 218	/812156	sandstone	grey, mod.hard, mod. well sorted, fine-medium sandstone: lithic feldsarenite; faults abundant	Qz, plag, calcite veins, mud matrix, micro faulting. see appendix I(b).
10602	Saw 218A	/812156	sandstone	grey, mod.hard, poorly sorted, medium sandstone: lithic feldsarenite	Qz, biotite, opaques, calcite, rock fragments. see appendix I(b).
10606	Saw 224	/825156	sandstone	grey, mod.hard, mod. well sorted, fine-medium sandstone: lithic feldsarenite	Qz, plag, biotite, zircon. see appendix I(b).
10607	Saw 226	/826142	sandstone	grey, mod.hard, mod. well sorted, fine sandstone: lithic feldsarenite	Qz, plag, opaques, rock fragments, heavy minerals. see appendix I(b).
10608	Saw 230	/832134	sandstone	light grey, mod.hard, mod. well sorted, fine -medium sandstone: feldspathic litharenite	see appendix I(b).

C.U. Rock Catalogue No.	Project Field No.	Grid Reference	Rock Type	Hand-specimen Description	Thin-section Description
10610	Saw 242	/791153	sandstone	grey, mod.hard, mod. well sorted, calcite veined, fine sand-stone: lithic feldsarenite	Qz, plag, K-spar, calcite veins, mud matrix. see appendix I(b).
10611	Saw 245	/816119	sandstone	grey, mod.hard, mod. well sorted, fine sandstone: lithic feldsarenite	see appendix I(b).
10612	Saw 247	/875132	sandstone	grey, mod.hard, mod. well sorted, fine sandstone: lithic feldsarenite	see appendix I(b).
10613	Saw 179	/913144	tuff	white, mod.soft, tuff	tuffaceous texture
10616	Saw 249	/866138	tuff	red, mod.soft, mod. well sorted, veined tuff	tuffaceous texture
10617	Saw R2	/894153	ignimbrite (clast)	white phenocrysts in a dark grey fine grain groundmass, poorly sorted	Qz, albite, biotite, sanidine phenocrysts
Champagne Member:					
10581	Saw 86	/816159	limestone	light brown, mod.hard, mod. well sorted, fine-medium sandy limestone	Qz, plag, chert, ss. forams, *Inoceramus* fragments, echinoderm spines and plates, calcite cemented

C.U. Rock Catalogue No.	Project Field No.	Grid Reference	Rock Type	Hand-specimen Description	Thin-section Description
10588	Saw 176A	/781119	sandstone	light grey, mod.hard, mod. well sorted, cross laminated, fine sand-stone: calcite cemented, lithic feldsarenite	
10597	Saw 215	/816165	sandstone	light grey, mod.hard, mod. well sorted, fine-medium sandstone: lithic feldsarenite	Qz, plag, muscovite, rock fragments, opaques, calcite
10598	Saw 215A	/816165	sandstone	light grey, mod.hard, well sorted, fine sandstone: lithic feldsarenite	see appendix I(b).
10599	Saw 216A	/816162	sandstone	light grey, mod.hard, mod. well sorted, fine-medium sandstone: calcite cemented, lithic feldsarenite	
10600	Saw 217	/816159	sandstone	grey, mod.hard, mod. well sorted, calcite veined, fine sandstone: lithic feldsarenite	Qz, plag, K-spar, calcite veining. see appendix I(b).
10609	Saw 235	/771151	sandstone	light grey, mod.hard, poorly sorted, fine-medium sandstone: lithic feldsarenite	see appendix I(b).
10614	Saw 216	/816162	sandstone	grey, mod.hard, poorly sorted, fine-medium sandstone	Qz, plag, microcline, muscovite, chert, opaques, rock fragments, calcite cemented. see appendix I(b).

C.U. Rock Catalogue No.	Project Field No.	Grid Reference	Rock Type	Hand-specimen Description	Thin-section Description
10615	Saw 240	/784155	sandstone	light grey, mod.hard, poorly sorted, carbonaceous, medium sandstone: lithic feldsarenite; micro-faults	see appendix I(b).
10618	Saw M1	/770134	dacite (clast)	coarse, crystalline igneous	phenocrysts of plag, qz and biotite. chlorite
10619	Saw M2	/770134	limestone (clast)	light grey limestone	Qz, biotite, rock fragments, calcareous
10624	Saw BB2	/802146	rhyodacite (clast)	light coloured phenocrysts in dark groundmass, igneous	phenocrysts of qz, plag, K-spar, chlorite; tuffaceous with calcite veining
10625	Saw BB4	/802146	granite (clast)	pink, equigranular, igneous	holocrystalline, hypidiomorphic, graphic texture, qz, pink plag, microcline, calcite, opaques, chlorite
10627	Saw BB7	/802146	tuff (clast)	dark, tuffaceous	basaltic clasts, qz, plag, chlorite, epidote, tuffaceous texture, calcite veins
10628	Saw BB8	/802146	rhyodacite (clast)	light coloured phenocrysts in dark groundmass, igneous	plag, K-spar, chlorite, phenocrysts in dark groundmass
10629	Saw 300	/770134		black volcanic dike rock with biotite phenocrysts	biotite
10630	Saw 301	/816159	lamprophyre	black volcanic dike rock with biotite phenocrysts	biotite
Ouse Member:					
10587	Saw 169	/820168	sandstone	light grey, mod.hard, mod. well sorted, graded, fine sandstone: fossiliferous, lithic feldsarenite	Qz, plag, prismatic calcite fragments, heavy minerals
10594	Saw 213	/820167	sandstone	grey, mod.hard, well sorted, fine sandstone	Qz, plag, calcite, forams. see appendix I(b).
10595	Saw 213A	/820167	sandstone	dark grey, mod.hard, mod. well sorted, fine sandstone: lithic feldsarenite	
10596	Saw 214	/818166	sandstone	grey, mod.hard, mod. well sorted, graded bedding, very fine sandstone: lithic feldsarenite	Qz, plag, prismatic calcite framents, heavy minerals. see appendix I(b).
Wharfe Sandstone Member:					
10593	Saw 203	/826168	sandstone	light grey, mod.hard, mod. well sorted, very fine sandstone: lithic feldsarenite	Qz, plag, biotite, chlorite, heavy minerals, opaques
10603	Saw 219	/823170	sandstone	light brown, mod.hard, mod. well sorted, fine sandstone: calcite cemented lithic feldsarenite	see appendix I(b).

C.U. Rock Catalogue No.	Project Field No.	Grid Reference	Rock Type	Hand-specimen Description	Thin-section Description
10604	Saw 220	/823170	sandstone	grey, moderately hard, mod. well sorted, medium sandstone: lithic feldsarenite	see appendix I(b).
Burnt Creek Formation:					
10575	Saw 18A	/824160	sandstone (clast)	grey, mod.hard, mod. well sorted, bio-turbated, very fine sandstone: lithic feldsarenite	Qz, plag, prismatic calcite fragments, heavy minerals
10576	Saw 18B	/824160	conglomerate (clast)	white, mod.soft, poorly sorted, calcareous conglomerate	ss and ms clasts, almost totally replaced by calcite
10577	Saw 18C	/824160	limestone (clast)	light brown, mod.hard, poorly sorted, mottled limestone	Qz, plag, microcline, ss and ms clasts, calcite veins, secondary calcite and chlorite
10578	Saw 18D	/824160	sandstone (clast)	light brown, mod.hard, poorly sorted, pebbly, calcareous sandstone	
10579	Saw 30	/824161	siltstone	dark grey, mod.hard, mod. well sorted, carbonaceous siltstone	Qz, plag, K-spar, fine grained
10605	Saw 221	/823162	sandstone	grey, mod.hard, mod. well sorted, carbon-aceous, well bedded, medium sandstone: calcite cemented feld-spathic litharenite	see appendix I(b).
10620	Saw BC1	/843168	granio-diorite (clast)	leucocratic, equi-granular, igneous	Qz, plag, microcline
10621	Saw BC2	/843168	ignimbrite (clast)	light coloured pheno-crysts in dark groundmass, poorly sorted	Qz, microcline phenocrysts in a fine grain glassy matrix. Ignimbritic texture
10622	Saw BC3	/843168	granite (clast)	white, equigranular, igneous	Qz, K-spar, biotite, calcite
10623	Saw BC4	/843168	tuff (clast)	leucrocratic, very fine groundmass, quartz veined	tuffaceous texture
10631	Saw 222	/824160	sandstone	grey, mod.hard, carbonaceous, medium sandstone	see appendix I(b)

I(b) Point Count Data for Sandstones of all Formations

Field #	218	242	218A*	224	230	226*	245	247	235	240	215A	217	216*	213	214*	221	222
Cant.Univ.sample #	10601	10610	10602	10606	10608	10607	10611	10612	10609	10615	10598	10600	10614	10594	10596	10605	10631
Formation	Cov. Saw	Cov. Saw	Cov. Saw	Pikes Saw	Pikes Saw	Pikes Saw	Glen Saw	Glen Saw	Ch	Ch	Ch	Ch	Ch	O	O	BC	BC
Grid Reference	812156	791153	812156	825156	832134	826142	816119	875132	771151	784155	816165	816159	816162	820167	818166	823162	824160
Av.grain size (mm)	0.2	0.5	0.3	0.2	0.3	0.2	0.2	0.2	0.2	0.3	0.2	0.1	0.2	0.1	0.1	0.2	0.2
Points counted	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300
% Quartz	26.6	27.0		30.6	18.9		26.0	30.6	28.0	25.6	20.6	30.0		26.0		27.0	30.6
Polycrystalline qz	3.3	3.3		4.0	4.6		6.0	2.6	5.0	2.3	4.6	1.0		0.3		5.6	3.0
Plag.	22.0	18.3		17.0	8.0		20.6	15.3	19.6	22.0	23.6	20.3		18.6		15.6	15.0
K-spar	3.6	9.6	8.3	7.0	8.3	8.0	4.0	8.0	5.3	9.6	7.6	5.0	8.3	3.0	5.0	3.3	9.3
Lithic fragments	20.3	19.3		17.6	24.6		19.3	12.3	20.6	21.6	18.3	14.3		13.3		25.0	18.0
Detrital mica	0.3	1.0		3.0	0.6		4.0	3.0	1.6	1.6	3.3	1.0		0.6		0.6	
Opaques	3.6	1.3		2.0	5.0		3.3	9.0	2.3	3.0	5.6	9.0		8.3		2.6	2.3
Others	2.3	5.6		2.3	4.3		3.3	3.3	3.3	1.6	2.3	10.3		6.6		2.0	1.3
Matrix	17.3	14.3		16.3	25.3		13.3	15.6	14.0	12.0	13.6	19.0		23.0		18.0	20.3
Q	29.9	30.3		34.6	23.5		32.0	33.2	33.0	27.9	25.2	31.0		26.3		32.6	33.6
F	25.6	27.9		24.0	16.3		24.6	23.3	24.9	31.6	31.2	25.3		21.6		18.9	24.3
R	20.6	19.3		17.6	24.6		19.3	12.3	20.6	21.9	18.3	14.3		13.3		25.0	18.0

* Stained for K-spar only as a check on staining procedure.

APPENDIX II : Fossil Record Information

This Appendix lists all the fossil record file numbers, species lists and ages for collections made during this thesis. Section (a) lists all palynological age determinations while section (b) lists all macropaleontological age determinations. The fossil collections are housed at New Zealand Geological Survey, Lower Hutt. The geological map of the Clarence River - Kekerengu River area (Plate 1) displays collection localities.

Abbreviations used :

Saw. - Ritchie 1986 field number
G.S. - NZ Geological Survey sample number

II(a) Palynological Age Determinations, Sheet P30
J.I. Raine, G.J. Wilson

Report GJW 153/85; JIR 12/85
File No. P30/774
September 1985

This series of samples, from the Kekerengu-Coverham area, was submitted by D.D. Ritchie (Canterbury University). Full species lists are attached.

P30/f199 (L12174) - Burnt Creek Formation - (Saw 44)

Low yield of miospores, very low of dinoflagellates; preservation fair; miospore colour red-brown.

Oligosphaeridium complex was the only dinoflagellate recognised; miospores include *Cicatricosisporites cuneiformis* (Cn-Mp), but nothing else of stratigraphic importance.

Age : Cn-Mp (dated by macrofauna at Rt).

P30/f201 (L12173) - ?Burnt Creek Formation - (Saw 28)

Moderate yield of miospores and dinoflagellates; preservation good; miospore colour deep yellow (lower rank than P30/f199). Dinoflagellates comprise *O. complex*, *Endoceratium* cf. *turneri*, *Odontochitina costata*, *Diconodinium multispinum*, *Odotochitina operculata*, *Cyclonephelium* cf. *densebarbatum*, *Millioudodinium* sp., suggesting a Cm-Cn age, probably the *Endoceratium turneri* Zone.

Among a number of miospore species identified, *Foraminisporis dailyi*, *Lycopodiacidites bullerensis*, *Neoraistrickia neozealandica*, *Lycopodiumsporites nodosus*, *Contignisporites multimuratus* are suggestive also of a pre-Raukumara age, being more typical of the *Lcyopodiacidites bullerensis* Assemblage of U-Cm age.

Age : Cm-Cn, probably Cm

P30/f202 (L12172) - Sawtooth Group - Pikes Block (Saw 101a)

A very low yield of miospores and dinoflagellates; preservation fair to poor; miospores brown in colour.

One specimen of *Odontochitina operculata* seen, establishing a Cretaceous age (U-M). The miospores do not assist further in establishing the age.

Age : U-M

P30/f203 (L12171) - Burnt Creek Formation - (Saw 31)

Moderate yield of well-preserved dinoflagellates, with less adundant miospores; miospore colour deep yellow. Dinoflagellates include *Diconodinium psilatum*, *Ascodinium* cf. *parvum*, *Microdinium ornatum*, *Odontochitina operculata*, *Endoceratium ludbrookiae*, *Cribroperidinium edwardsii*, *Cleistosphaeridium* sp., indicating the *E. ludbrookiae* Zone of Cm-Ra age.

Miospores comprise gymnospermous species: *Podocarpidites* sp., *Araucariacites australis*, *Microcachryidites antarcticus*, *Trichotomosulcites subgranulatus*, plus a few pteridophytes: *Gleicheniidites senonicus*, *Lycopodiumsporites* sp. and *Perotrilites granulatus* (Cu- early R?); not particularly diagnostic, but consistent with *Trichotomosulcites subgranulatus* Assemblage (late Cm-Ra), and different from the more pteridophyte-dominated assemblage of P30/f201, which appears to be older.

Age : late Cm-Ra (have a Cu-Cn date for macrofauna here ∴ age = Cm-Cn)

P30/f217 (L12209) - Champagne Member - (Saw 164)

Moderate yield of miospores and dinoflagellates; preservation good; miospore colour deep yellow.

The dinoflagellate population is dominated by *Diconodinium psilatum*, with other species including: *Odontochitina operculata, Endoceratium turneri, Cribroperidinium* cf. *edwardsii, Ologosphaeridium complex, Endoceratium* cf. *ludbrookiae, Diconodinium multispinum, Spiniferites ramosus, Cleistosphaeridium* sp. The age indicated by this assemblage is Cm-Cn, probably *Endoceratium turneri* Zone. The miospores include a variety of lycopods: *Lycopodiacidites bullerenis, Dictyotosporites speciosus* (U-Cm), *D. complex, Lycopodium cristatus, Ceratosporites equalis;* together with a few other taxa: *Leptolepidites verrucatus* (Jurassic to Cn), *Osmundacidites* sp., *Pdodcarpidites* sp., *Callialasporites segmentatus, Cyathidites minor, Corollina* sp., *Annulispora folliculosa, Biretisporites potoniaei, Cicatricosisporites australiensis.* The assemblage is typical of the Lower Cretaceous *Lycopdiacidites bullerenis* Assemblage (U-Cm).

Age : Cm

P30/f250 (L12261) - Sawtooth Group - Pikes Block (Saw 223)

A low yield, mainly of dinoflagellates; fair preservation. The dinoflagellates comprise mainly a distinctive apparently undescribed species of *Senoniasphaera*, very similar to forms recorded from the Korangan of Maccoyella Ridge, Raukumara Peninsula. The presence of *Odontochitina operculata* confirms a Cretaceous rather than a Late Jurassic Age.

One miospore was tentatively identified, possibly a reworked Triassic-Jurassic species.

Age : probably Uk

P30/f251 (L12262) - Sawtooth Group - Glencoe Block (Saw 231)

Very low yield. Only a single dinoflagellate cyst could be recognised, apparently the same ?*Senoniasphaera* as in P30/f250.

Age : n.d., possibly Uk

P30/f252 (L12263) - ?Split Rock Formation - Champagne Member (Saw 232)

Very low yield, only dinoflagellates being observed. Species include *Ascodinium acrophorum*, *Diconodinium psilatum*, *Diconodinium* cf., *dispertitum*.

Age : Cm-Cn, *Endoceratium turneri* or *E. ludbrookiae* Zone

P30/f253 (L12264) - ?Split Rock Formation - Champagne Member (Saw 235)

Rich yield of miospores, with less abundant dinoflagellates; good preservation; miospore colour light orange-yellow.

Dinoflagellates include *Diconodinium multispinum*, *D. psilatum*, *Cribroperidinium* sp., *Odontochitina operculata*, suggesting the *Endoceratium turneri* or *E. ludbrookiae* Zones (Cm-Cn).

The diverse miospore assemblage includes at least three different populations : a contemporaneous (mid-Cretaceous) population with light yellow fluorescence in blue-violet irradiation; a population with orange-red fluorescence, mainly *Callialasporites* spp. and thus likely to be Late Jurassic; and a third population with weak red-brown fluorescence comprising Triassic species. Miospores of the first population include the following stratigraphically significant species: *Crybelosporites striatus* (Cu-Cn), *Leptolepidites verrucatus* (Jurassic-Cn), *Contignisporites glebulentus* (?Jurassic-Cn), *Dictyotosporites speciosus* (U-Cm). These taxa, together with the abundance and diversity of lycopodiaceous taxa, indicate the *Lycopodiacidites bullerensis* Assemblage (U-Cm).

Age : Cm

P30/f254 (L12265) - ?Split Rock Formation - Champagne Member (Saw 236)

Very low yield; preservation poor; miospores deep yellow. Dinoflagellates include one possible specimen of *Ascodinium* sp. and *Diconodinium multispinum*.

Only one miospore, *Cibotiidites volkheimerii*, was identified. This has little age significance.

Age : n.d.

P30/f255 (L12266) - Sawtooth Group - Glencoe Block (Saw 248)

Low yield of very dark carbonaceous detritus. No identifiable palynomorphs.

Age : n.d.

REF.	Fossil Record No.
1	P30/f199
2	P30/f201
3	P30/f202
4	P30/f203
5	P30/f217
6	P30/f250
7	P30/f251
8	P30/f252
9	P30/f253
10	P30/f254
11	P30/f255

TABLE OF SPECIES OCCURRENCE

	1	2	3	4	5	6	7	8	9	10	11
Group: DINOPHYCEAE											
Ascodinium acrophorum								*			
Ascodinium cf. parvum				*							
Ascodinium sp.										*	
Cleistosphaeridium sp.				*	*	*					
Cribroperidinium edwardsii				*							
Cribroperidinium cf. edwardsii					*						
Cribroperidinium sp.									*		
Cyclonephelium cf. densebarbatum		*									
Diconodinium cf. dispertitum								*			
Diconodinium multispinum		*			*				*		
Diconodinium psilatum				*	*			*	*		
Diconodinium sp.										*	
Endoceratium ludbrookiae				*							
Endoceratium cf. ludbrookiae					*						
Endoceratium turneri					*						
Endoceratium cf. turneri		*									
Microdinium ornatum				*							
Millioudodinium sp.		*									
Odontochitina costata		*									
Odontochitina operculata		*	*	*	*	*			*		
Oligosphaeridium complex	*	*			*						
Oligosphaeridium pulcherrimum									*		
Oligosphaeridium sp.						*					
Senoniasphaera 'raukumaraensis' MS.						*					
?Senoniasphaera sp.							*				
Spiniferites ramosus					*						
Group: POLLENITES											
Alisporites australis									*		
Alisporites lowoodensis									*		
?Angiospermae									*		
Araucariacites australis		*		*							
Callialasporites dampieri									*		
Callialasporites segmentatus					*				*		
Callialasporites sp.		*									
Chordasporites australiensis									*		
Corollina sp.		*			*				*		
Equisetosporites steevesii									*		
Microcachryidites antarcticus		*		*							
?Phyllocladidites mawsonii	*										
Podocarpidites ellipticus									*		
Podocarpidites sp.		*	*	*	*						
Taxodiaceaepollenites hiatus	*										
Trichotomosulcites subgranulatus				*							
Vitreisporites signatus									*		
Group: SPORITES											
Aequitriradites spinulosus									*		
Annulispora folliculosa					*						
Baculatisporites comaumensis		*		*							
Biretisporites potoniaei					*						
Ceratosporites equalis		*			*						
Cibotiidites tuberculiformis		*									
Cibotiidites volkheimeri									*	*	
Cicatricosisporites australiensis		*			*				*		
Cicatricosisporites cf. cuneiformis	*										
Contignisporites cooksoniae									*		
Contignisporites glebulentus									*		
Contignisporites multimuratus		*									
?Couperisporites sp.									*		
Crybelosporites striatus									*		
?Crybelosporites sp.									*		
Cyathidites australis		*							*		
Cyathidites minor		*	*		*				*		
Dictyophyllidites sp.	*										
Dictyotosporites complex					*						
Dictyotosporites speciosus					*				*		
?Dictyotosporites sp.		*									
Foraminisporis asymmetricus	*										
Foraminisporis dailyi		*							*		
Foraminisporis wonthaggiensis	*										
Gleicheniidites senonicus		*		*							
Indospora clara		*									
Leptolepidites verrucatus					*				*		
?Leptolepidites verrucatus		*									
Lycopodiacidites bullerensis		*	*		*				*		
Lycopodiacidites cristatus					*						
Lycopodiumsporites austroclavatidites					*				*		
Lycopodiumsporites circolumenus					*						
Lycopodiumsporites nodosus		*			*				*		
Lycopodiumsporites cf. reticulumsporites									*		
Lycopodiumsporites sp.	*			*							
Neoraistrickia neozelandica		*									
Nevesisporites limatulus									*		
Osmundacidites sp.					*						
Osmundacidites wellmanii	*								*		
Perotrilites granulatus				*							
Punctatosporites scabratus									*		
?Uvaesporites verrucosus						*					
Verrucosisporites sp.			*								

II (b) Macropaleontological Age Determinations : I.G. Speden

Fossil Record No.	Formation	Field No.	Grid Ref.	Species List	Age
P30/f260	Champagne	G.S. 14031	P30/816162	*Inoceramus sp. indent.*	n.d.
P30/f261	Champagne	G.S. 14028	P30/815162	*Inoceramus sp. ex gr. ipuanus - kapuus*	Cu-Cm
P30/f262	Champagne	G.S. 14026	P30/815161	*Inoceramus sp. ex gr. ipuanus - kapuus*	Cu-Cm
P30/f263	Champagne	G.S. 14029	P30/816161	*Inoceramus sp. indent.*	n.d.
P30/f264	Ouse	G.S. 14027	P30/818165	*Aucellina euglypha* Woods *Inoceramus sp. indent.* *Ident. gastropod*	Cm
P30/f204	Burnt Creek	Saw 31 G.S. 13958	P30/823163	*Inoceramus ex gr. concentricus - tawhanus* Or *Inoceramus ex gr. ipuanus - kapuus*	Cu-Cn
P30/f200	Burnt Creek	Saw 44 G.S. 13957	P30/867165	*Inoceramus nukeus* Wellman *echinoid*	Rt

APPENDIX III : Measured sections

In addition to the measured sections for Champagne, Ouse and Wharfe Members and Burnt Creek Formation which appear in Chapter II, the data was plotted on New Zealand Geological Survey Cretaceous - Cenozoic Project measured section detail sheets. These are reproduced in this appendix along with a graphic symbol key for all the measured sections in this thesis.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: ~~1 cm : 1 m (1 : 100)~~ 1 cm : 10 m (1 : 1000) ~~1 cm : 50 m (1 : 5000)~~

LOCALITY: Section through lower part of Champagne Member of Split Rock Formation, Ouse Stream, Coverham, Marlborough

GEOLOGIST(S): D. D. Ritchie

P30 NZMS 260 sheet | c serial number | – horizon | remeasurement?

DATE OF MEASUREMENT: 6 day 5 month 1985 year

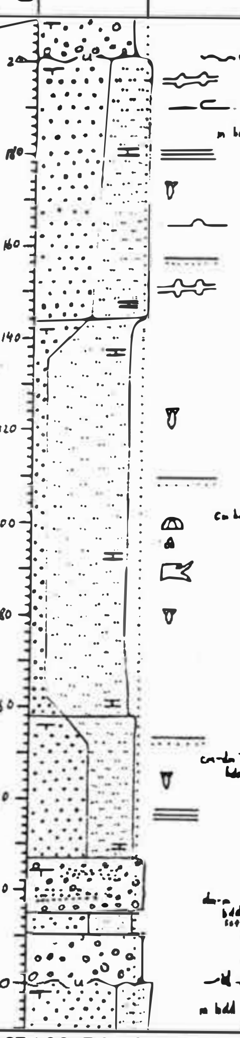
GRID REFERENCES: (metric) 1975 map date | BASE OF SECTION: 812 easting, 156 northing | TOP OF SECTION: 817 easting, 164 northing

DRILLHOLES: Has thickness been corrected for dip? YES, NO

METHOD OF MEASUREMENT: tape and map-scale. (approximate)

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Petrological data	Paleontological data	'P' number	Disturbance	Scale (metres)	Description
	Ouse Mb.			mfl P30/f68 (Cm)			Basal conglomerate of Ouse Member of Split Rock Formation
Cm	Champagne Member	sms 215 Light grey, mod. hard, mod well sorted, fine-med. sst : lithic feldsarenite. →				200	Sandstone/Siltstone 43m m bdd, ~~moderately hard~~, light grey, slightly wthd, graded bedding, sst beds with gritty bottoms, mud-chip breccia, flame structures, sand injection structures, convoluted bedding, ssts boudinaged, intense mesoscopic faulting.
	L2	flysch-like alternating sst/sst: sandstone dominant				180, 160	
		Heavy minerals include: pyrite, semi-opaque debris, epidote, clinopyx, apatite, garnet, biotite, chlorite, ilmenite, pumpellyite, tourmaline, rutile, barite. (after Smale).		Mfo f261 (Cu-Cm)	Σ	140, 120	Sandstone/Siltstone 86m cm bdd; ss moderately hard, well graded; Siltstone moderately soft, dark grey, slightly wthd, shattered, occasional *Inoceramus*, infconic dikes, calcified sst lenses, mesoscopic folding, intensely normal faulting. Beds have been losenged and deformed to the extent of forming a 'broken formation'. The Champagne Member here makes up the eastern limb of the Ouse Anticline. Deformation is due to formation of this structure and also the sections proximity to the 'Ouse Thrust.'
	L3	flysch-like alternating ss/sst: siltstone dominant		Mfo f262 (Cu-Cm)	Σ	100	
		sms 88: from calcareous lense → Thin-section: *Inoceramus* fragments, echinoderm spines + plates, forams, chert, qz, calcite cemented sst.				80	
				Mfo f263 (Cu-Cm)		60	
	L2					40	Sandstone/Siltstone 31m cm-dm bdd (thinning upwards), moderately hard, well graded, sst beds thin into above beds
	L1	conglomerate				20	Conglomerate 27m Interbdd. with dm-m bdd sst.; matrix supported crs pbb cgl.; majority of clasts sst, also ignimbrite, volcanic igneous, quartzite clasts. Conglomerate consists of 2 beds of cgl. separated by 2-3m of flysch.
Cu?						0	discomformity — Sandstone/Siltstone m bdd; moderately hard, grey, poorly sorted fine-medium sandstone (Sawtooth Group (Coverham Ss))



Structural data: 60; shear-like step-faulting; predominant faulting direction 050°; 80

PAGE 1 OF 1

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION:

SCALE: ~~1 cm : 1 m (1 : 100)~~ 1 cm : 10 m (1 : 1000) ~~1 cm : 50 m (1 : 5000)~~

LOCALITY: Ouse Stream, nr Coverham, Marlborough. Section through Ouse Member of Split Rock Formation, Ouse Stream

GEOLOGIST(S): D.D. Ritchie

P30	c	–		DATE OF MEASUREMENT: 7 / 3 / 1985
NZMS 260 sheet	serial number	horizon	remeasurement?	day / month / year

GRID REFERENCES: (metric)

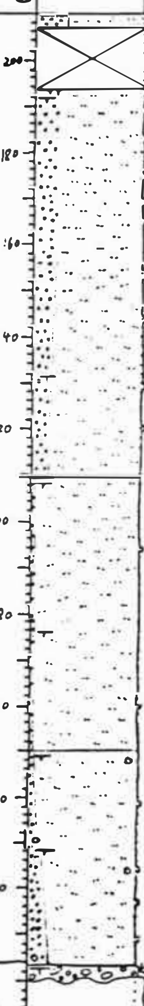
19 75	817	164	823	169
map date	BASE OF SECTION easting	northing	TOP OF SECTION easting	northing

DRILLHOLES: Has thickness been corrected for dip? YES, NO

METHOD OF MEASUREMENT: tape and compass

Elevation of drillhole collar ____ metres a.s.l.

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
						200			13m not exposed	
			benthonic forams. Polymorphinid. seen in thin-section			180				
		L3 → Flysch like alternating ss/zst				160		cm-bd	Deformation; faulting and folding, highly fossiliferous, Inoceramus	faulting at 020/090 dominant
		hand-specimen: sst: Light grey, mod. hard, mod. well srtd graded, fine sd. : fossiliferous, lithic feldsarenite	Aucellina on sst bed bases			140			Siltstone/Sandstone 206m sst cm bd up to 20cm thick, graded, calcareous cemented; Inoceramus; Aucellina on bed bases; massive zst becoming more sandy up-section; glauconitic	
						120				
Cm	Ouse Member					100			Siltstone 50m. massive, shattered and crumbly with scattered Inoceramus; alternating layers of zst with Inoceramus and siltstone without Inoceramus (m-scale); calcite veining; very strong cleavage at 035°/090.	67°
		L2B → massive zst with rare graded ss beds	Inoceramus widespread	Mfa f264 (Cm)		80				
						60		moss		strong cleavage
		L1 = Conglomerate				40			Siltstone 47m. moderately hard, dark grey, slightly wthd, crumbly, with Inoceramus shellbed; cm-bd; sandstone beds well graded med-crs sst; occasional pebbles, intense normal faulting.	faulting at 020/090 dominant
		L2A → massive zst with Inoceramus shell-bed	shellbed of Inoceramus			20			Conglomerate 3m, moderately hard, light grey, slightly wthd, well rnd to angular, clast supported, crs. pebble conglomerate with sandstone matrix; occuring only locally at base of Ouse Fmn.;	
		Conglomerate Clasts 99% locally derived sst and zst. 1% igneous clasts. ~~rare~~ boulder clasts, ~~carbonaceous~~ rip-up sst. beds containing Inoceramus fragments		m81 f68 (Cm)		0			~~~ unconformity ~~~ BASE - forms an disconformity with m-bd ssts of Champagne Member	
	L1	← Champagne Member of Split Rock Formation								



PAGE 1 OF 2

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION:

~~SCALE: 1 cm : 1 m (1 : 100)~~ 1 cm : 10 m (1 : 1000) ~~1 cm : 50 m (1 : 5000)~~

LOCALITY: Ouse Stream, near Coverham, Marlborough. Section through Ouse Member of Split Rock Formation, Ouse Stream

GEOLOGIST(S): D. D. Ritchie

P30 NZMS 260 sheet | c serial number | – horizon | remeasurement?

GRID REFERENCES: (metric) 19 75 map date

BASE OF SECTION: 817 easting, 164 northing

TOP OF SECTION: 823 easting, 169 northing

METHOD OF MEASUREMENT: tape and compass

DATE OF MEASUREMENT: 7 day, 3 month, 19 85 year

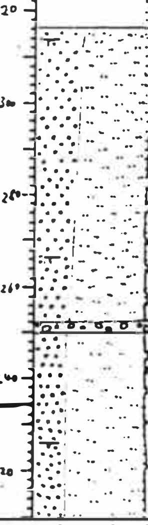
DRILLHOLES:

Has thickness been corrected for dip? YES, NO

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	Description
Cm	Wharfe Sandstone Member			mf1 f 70 (Cm)			TOP – Gradational contact with Wharfe Sandstone Member
	Ls					320	↑ Sandstones gradually thickening as contact is approached. Deformation in the top 30m; slumping, mesoscopic steeply plunging folds.
						300	
Cm	Ouse Member	Heavy minerals include: Pyrite, semi-opaques, epidote, sphene, apatite, ilmenite, garnet, chl, biot. zircon, Clinopyx. (after Smale).				280	Siltstone/Sandstone (cont) 206m. Siltstone as below; sst cm–dm bd gradually thickening up-section; noticeably thickening immediately above cgl.; convoluted bdd; normal faults.
						260	Conglomerate 2m, locally derived
				mf1 f 67 (Cm)		240	
	Ls					220	

GRAPHIC LOG:



Additional graphic: dm bd; cm–dm bd

Structural data: N

PAGE 2 OF 2

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ______ SCALE: ~~1 cm : 1 m (1:100)~~ 1 cm : 10 m (1 : 1000) ~~1 cm : 50 m (1 : 5000)~~

LOCALITY: Wharfe Stream ; near Coverham, Marlborough. Section through Wharfe Sandstone Member of Split Rock Formation Wharfe Stream Gorge.

GEOLOGIST(S): D. D. Ritchie

P30	c	-	
NZMS 260 sheet	serial number	horizon	remeasurement?

DATE OF MEASUREMENT: 10 (day) 3 (month) 19 85 (year)

GRID REFERENCES: (metric)

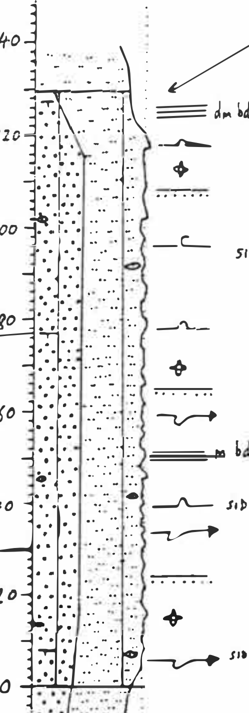
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 75 *	826	166 *	826	169 *

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: tape and compass

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Samples taken and results: Petrological data	Samples taken and results: Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data (N ↑)
Cn	Swale Siltstone Member								TOP: Gradational contact with Swale Siltstone Member.	
?			Basal Swale Siltstone Member dated at Cm →			140			↑ sandstone beds thinning as contact approached.	
Cm	Wharfe Sandstone Member	Wharfe sst: Saw203; Handspecimen - Light grey, mod. hard, mod. well sorted, very fine sst : lithic feldsarenite.	mfl	P30/f81 (Cm)		120, 100, 80			Turbidites: Uniform turbidites with Bouma A-D well developed; Bouma C thickened (ie had several pulses of sandy sedimentation). No pelagic Bouma E interval present. Sandstone portion (Bouma A-D): Moderately hard, light grey, slightly wthd, well laminated, m-bdd (≤ 4m thick!), with syn-sedimentary convoluted bedding, climbing ripples, flute marks, rip-up mud clasts, water expulsion features and slump structures, carbonaceous (with coal lenses up to 1cm thick) med.- crs. sandstone with rare pebbles; diagenic sideritic lenses on base of beds; Ssts. occasionally scour into other ssts.	60
			mfl	P30/f70 (Cm)		60, 40, 20			Siltstone portion (Bouma D): Soft, dk. grey, slightly wthd, bioturbated siltstone.	62
						0			↑ Sandstones gradually thickening upwards until m-bedded. BASE: Gradational contact with Ouse Member.	
Cm	Ouse Mbr									



PAGE 1 OF 1

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION: ____________ SCALE: ~~1 cm : 1 m (1:100)~~ 1 cm : 10 m (1 : 1000) ~~1 cm : 50 m (1 : 5000)~~

LOCALITY: Otter's Stream ; Section through Burnt Creek Formation

GEOLOGIST(S): D.D. Ritchie ; J. Armitage

P30	C	–		DATE OF MEASUREMENT: 4 / 3 / 19 25
NZMS 260 sheet	serial number	horizon	remeasurement?	day / month / year

GRID REFERENCES: (metric)

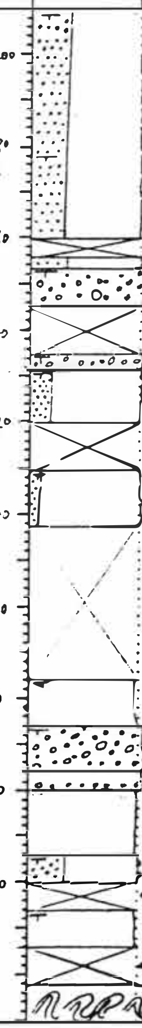
19 75	BASE OF SECTION: 825	159	TOP OF SECTION: 820	163
map date	easting	northing	easting	northing

DRILLHOLES: Has thickness been corrected for dip? YES , NO

METHOD OF MEASUREMENT: tape and compass

Elevation of drillhole collar ______ metres a.s.l.

Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'f' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data N
		L5				200			← waterfall	64
						180			← fence	
						160		cm-bd	not exposed	
		L1				140			Conglomerate ~10m granule conglomerate; clasts predominately sst. and zst; rare boulders; passes up into interbedded sandstone and mudstone dm bedded.	
									not exposed	
Cm–Cn	Burnt Creek Formation	L5	mis-I.D.?	P30/f6673(R)		120			Mudstone/Sandstone 22m+ moderately hard; slightly wthd; bioturbation; contains *Inoceramus*; interbdd SST/MS : mudstone predominates; calcareous lenses	15
						100		cm-bd	not exposed	
		L2				80			not exposed	
						60				
		L4							Conglomerate 17m ; Moderately hard, slightly weathered, very coarse pebble to boulder conglomerate; Lower conglomerate 2m thick, Upper cgl 15m thick. Clasts include : greensand, sandstone, travertine, rip-up clasts of sst/zst interbd; matrix of mst. to med. grey zst; jumbled and disrupted – olistostrome orig	62
		L5, L4				40				
		L2							not exposed	
		L5				20			Sandstone/Mudstone 7m+ med–crs. bd light grey sst ; mud chip breccia	60 FH
		L2						mass	Mudstone 25m+, grey, massive mudstone ; shattered	
						0			Angular unconformity between Burnt Ck. Fmn. and massive sst. of Sawtooth Group.	
		Sawtooth Group Pikes Seament							unconformity	
									BASE – not exposed locally here, probably faulted. Base of Burnt Creek elsewhere represented by a 10m± v.crs. rubble cgl.	



PAGE 1 OF 3

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION:

SCALE: ~~1 cm : 1 m (1:100)~~ 1 cm : 10 m (1 : 1000) ~~1 cm : 50 m (1 : 5000)~~

LOCALITY: Lottei's Stream; Section through Burnt Creek Formation

GEOLOGIST(S): D.D Ritchie · J. Armitage

P30	C	–	
NZMS 260 sheet	serial number	horizon	remeasurement?

DATE OF MEASUREMENT: 4 (day) 3 (month) 1985 (year)

GRID REFERENCES: (metric)

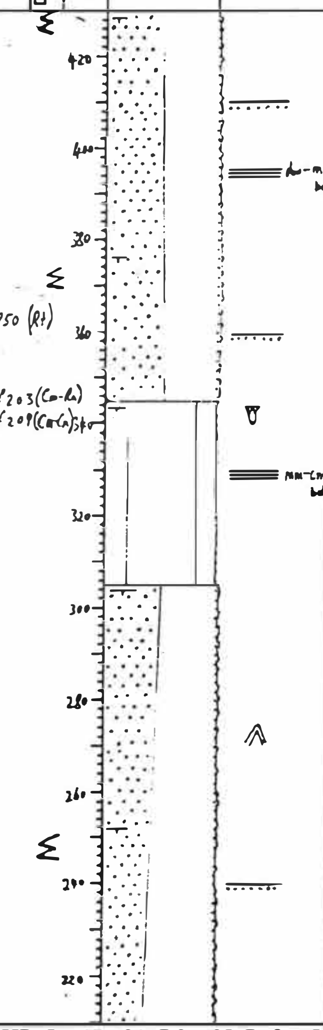
map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
1975	225	159	220	163

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ___ metres a.s.l.

METHOD OF MEASUREMENT: tape and compass

Stage	Formation	Petrological data	Paleontological data	"F" number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data
Cm – Cn	Burnt Creek Formation								see description above.	
	Ls		{MIS-I.D.? → Rt	P30/f6750 (Rt)						
		Probable date Cm–Cn	microfloral date g. co. gr. [illegible] or g. eq. gr. [illegible]	P30/f203 (Cm-Rn) P30/f209 (Cm-Cn)					Mudstone 40m moderately hard, grey, slightly weathered, well bedded; *Inoceramus*; carbonaceous mudstone.	
	Ls								sst cm – dm bdd; thickening upwards	75
	Ls								Sandstone/Mudstone 145m; moderately hard, grey, slightly wthd, well graded, very well cm-bdd, flute casts, cone-in-cone structures within ≤20cm thick calcareous sst lenses, *Inoceramus*, interbedded sst/ms. Sst beds becoming gradually thicker up-section; Becoming more deformed up section, mesoscopic folding and faulting.	



START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

MEASURED SECTION DETAIL SHEET

REGION:

SCALE: ~~1 cm : 1 m (1:100)~~ 1 cm : 10 m (1 : 1000) ~~1 cm : 50 m (1 : 5000)~~

LOCALITY: Loffer's Stream ; Section through Burnt Ck. Fmn

GEOLOGIST(S): D.D.Ritchie ; J Armitage

NZMS 260 sheet	serial number	horizon	remeasurement?
P30	c	–	

GRID REFERENCES: (metric)

map date	BASE OF SECTION easting	BASE OF SECTION northing	TOP OF SECTION easting	TOP OF SECTION northing
19 75	825	159	820	163

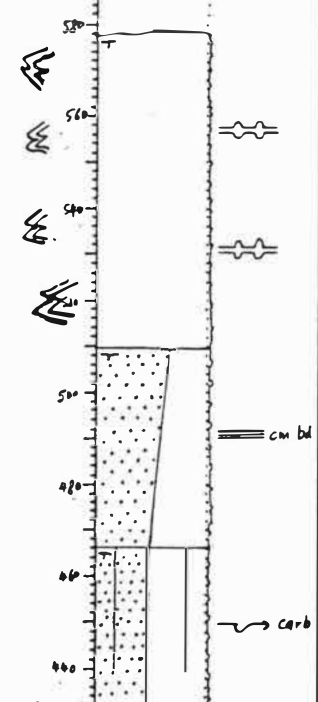
METHOD OF MEASUREMENT: tape and Compass

DATE OF MEASUREMENT: 4 (day) 3 (month) 19 85 (year)

DRILLHOLES: Has thickness been corrected for dip? YES , NO

Elevation of drillhole collar ______ metres a.s.l.

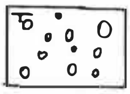
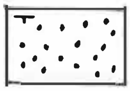
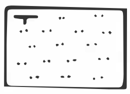
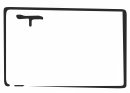
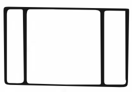
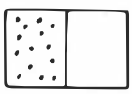
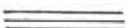
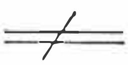
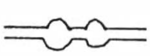
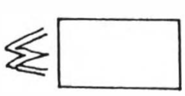
Stage	Formation	Samples taken and results: Petrological data	Paleontological data	'P' number	Disturbance	Scale (metres)	GRAPHIC LOG	Additional graphic	Description: Name of rock; hardness and cementation; colour; weathering and sedimentary structures (including biogenic); fossils; texture (grain size, sorting, shape, roundness); accessory minerals; preliminary assessment of environment of deposition	Structural data ↑N
Cm	Champagne Member									
	Burnt Creek Formation	Thrust Fault Contact				580			TOP – Fault zone contact with cm-bd interbedded sst/zst of Champogni Member : Thrust Fault	
						560			Fault Zone : – Highly deformed; bedding lozenged; boudinaged ; mesoscopic folding and faulting.	major thrust fault 040°/dips steeply to West. + associated deformation
		Ls				540				
						500		cm bd	Sandstone/mudstone 50m – cm bdd; sst/ms interbedded; coarsening upward section to dm-bedded.	
		Ls				480				
						460		carb	Sandstone / Mudstone 115m ; moderately hd, grey, slightly wthd., well bedded, often carbonaceous, flute casts; well graded, dm – m interbedded sst/ms ; deformation increasing up-section	75
						440				



PAGE 3 OF 3

START PLOTTING AND NUMBERING SAMPLES AT THE BOTTOM OF THE SHEET. EXACT LOCATION OF THIS MEASURED SECTION TO BE SHOWN ON MAP ON BACK OF THIS SHEET.

KEY TO MEASURED SECTIONS

	conglomerate
	sandstone
	siltstone
	mudstone
	carbonaceous
	interbedded (50% ss / 50% ms)
	well bedded
	massive
	graded bedding
	slumping
	flute casts
	bioturbation
	bivalves
	foraminifera
	cone-in-cone
	boudinage
	convolute bedding
	flame structures
	echinoids
	highly disturbed bedding

SAW	14	58	121	121A	121B	178	179	185	198
C.U.#	10573	10580	10583	10584	10584	10589	10613	10590	10591
SiO_2	67.701	62.411	54.886	58.532	47.362	60.873	71.541	63.167	68.455
TiO_2	0.362	0.432	0.321	0.408	0.307	0.505	0.220	0.137	0.266
Al_2O_3	15.900	15.821	20.478	18.194	16.950	17.589	13.578	17.536	13.106
Fe_2O_3	2.019	3.633	1.695	2.344	2.017	3.138	0.728	0.948	2.281
MnO	0.028	0.062	0.020	0.038	0.224	0.058	0.018	0.034	0.055
MgO	0.530	0.881	0.483	0.780	0.559	0.848	0.244	0.101	0.526
CaO	4.152	7.240	10.551	9.260	16.463	7.011	5.777	8.714	6.663
Na_2O	2.626	0.461	0.484	0.485	0.470	1.553	0.997	0.028	0.622
K_2O	2.014	0.694	0.636	0.333	0.551	0.751	0.548	0.415	0.339
P_2O_5	0.066	0.129	0.095	0.183	0.087	0.120	0.070	0.039	0.075
Loss	4.560	7.770	10.930	9.770	15.350	7.280	6.690	9.200	7.160
Total	99.959	99.535	100.579	100.327	100.340	99.725	100.411	100.319	99.548
SiO_2 (recalc)	70.966	68.012	61.223	64.636	55.727	65.848	76.334	69.324	74.095
Sr	613	715	554	434	488	474	499	398	338
Rb	67	23	21	12	19	34	24	6	13
Y	24	23	31	14	31	46	27	22	21
Pb	31	27	48	43	35	36	23	37	22
Th	17	20	35	22	24	25	26	34	14
Ga	12	18	17	19	16	17	7	20	17
Zr	233	166	228	172	188	334	120	216	179
Nb	17	9	11	5	12	12	14	14	4
Ba	89	297	739	41	118	150	186	207	53
V	24	50	35	45	36	45	18	16	31
Cr	12	23	14	13	18	26	9	3	13
Nd	25	32	28	23	21	38	37	19	24
Ce	52	64	59	46	59	67	89	54	75
Zn	75	65	45	64	65	92	23	47	53
Ni	7	10	6	8	10	7	2	1	2
La	21	28	29	23	24	29	42	18	28

Appendix IV Geochemical data for 9 tuff analyses